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# The National Nanotechnology Initiative: Overview, Reauthorization, and Appropriations Issues

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# Summary

Nanotechnology—a term encompassing the science, engineering, and applications of submicron materials—involves the harnessing of unique physical, chemical, and biological properties of nanoscale substances in fundamentally new and useful ways. The economic and societal promise of nanotechnology has led to investments by governments and companies around the world. In 2000, the United States launched the world's first national nanotechnology program. From FY2001 through FY2014, the federal government invested approximately $19.4 billion in nanoscale science, engineering, and technology through the U.S. National Nanotechnology Initiative (NNI). President Obama has requested $1.5 billion in NNI funding for FY2015. U.S. companies and state governments have invested billions more. The United States has, in the view of many experts, emerged as a global leader in nanotechnology, though the competition for global leadership is intensifying as countries and companies around the world increase their investments.

Nanotechnology's complexity and intricacies, early stage of development (with commercial pay-off possibly years away for many potential applications), and broad scope of potential applications engender a wide range of public policy issues. Maintaining U.S. technological and commercial leadership in nanotechnology poses a variety of technical and policy challenges, including development of technologies that will enable commercial scale manufacturing of nanotechnology materials and products, as well as environmental, health, and safety concerns.

Congress established programs, assigned responsibilities, and initiated research and development related to these issues in the 21st Century Nanotechnology Research and Development Act of 2003 (P.L. 108-153). Although many provisions of this act have no sunset provision, FY2008 was the last year of agency authorizations included in the act. Bills to amend and reauthorize the act were introduced in the 110th Congress and 111th Congress but were not enacted. No comprehensive reauthorization bill was introduced in the 112th Congress. In the 113th Congress, bills were introduced in the House and Senate that sought to amend the 21st Century Nanotechnology Research and Development Act. In the House bill, the National Nanotechnology Initiative Amendments Act of 2014 was incorporated as part of H.R. 4159, the America COMPETES Reauthorization Act of 2014, and referred to two committees. No further action was taken on the bill. In the Senate, the National Nanotechnology Initiative Amendments Act of 2014 was incorporated as part of S. 2757, the America COMPETES Reauthorization Act of 2014. S. 2757 was referred to the Committee on Commerce, Science, and Transportation and no further action was taken.

Proponents of the NNI assert that nanotechnology is one of the most important emerging and enabling technologies and that U.S. competitiveness, technological leadership, national security, and societal interests require an aggressive approach to its development and commercialization. Critics of the NNI voice concerns that reflect disparate underlying beliefs. Some critics assert that the government is not doing enough to move technology from the laboratory into the marketplace. Others argue that the magnitude of the public investment may skew what should be market-based decisions in research, development, and commercialization. Still other critics say that the inherent risks of nanotechnology are not being addressed in a timely or effective manner.

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# Introduction

Nanotechnology has been an issue of interest to Congress for a number of years, coming into focus in 2000 with the launch of the U.S. National Nanotechnology Initiative (NNI) by President Clinton in his FY2001 budget request to Congress. From FY2001 through FY2014, Congress appropriated approximately $19.4 billion for nanotechnology research and development (R&D). President Obama has proposed $1.5 billion in NNI funding for FY2015. The NNI's efforts have been directed at advancing understanding and control of matter at the nanoscale,[1] where the physical, chemical, and biological properties of materials differ in fundamental and useful ways from the properties of individual atoms or bulk matter.[2]

### Nanotechnology: A Description

The term "nanotechnology" is often used as an all-encompassing term for nanoscale science, engineering, and technology. Nanotechnology is the understanding and control of matter at dimensions of roughly 1 to 100 nanometers, the size-scale between individual atoms and bulk materials, where unique phenomena enable novel applications. A nanometer is one-billionth of a meter, or about the width of 10 hydrogen atoms arranged side-by-side in a line. Nanotechnology involves imaging, measuring, modeling, and manipulating matter at this size-scale.

At the nanoscale, the physical, chemical, and biological properties of materials can differ in fundamental and useful ways from the properties of individual atoms and molecules or bulk matter. Nanotechnology R&D is directed toward understanding and creating improved materials, devices, and systems that exploit these new properties.

Physicist Richard Feynman's remarks at the 1959 annual meeting of the American Physical Society are often cited as the first articulation of and vision for nanotechnology. Though he did not use the term nanotechnology in this speech, he spoke of controlling matter at the nanoscale and creating atomic-level machines, positing some of the applications that doing so might enable.

**Source:** *The National Nanotechnology Initiative Strategic Plan, 2004,* Nanoscale Science, Engineering, and Technology Subcommittee, National Science and Technology Council, Executive Office of the President, December 2004.

The development and application of nanotechnology—more fully explained below—across a wide array of products and industries holds the potential for significant economic and societal benefits. To capture these benefits, the United States will have to effectively address a variety of technical and policy challenges that stand as potential barriers to commercialization, including environmental, health, and safety (EHS) concerns and their implications for workplace, environmental, food, and drug regulations; development of standards, reference materials, and consistent nomenclature; development of new measurement methods and tools; effective technology transfer to the private sector; protection of intellectual property; availability, affordability, and patience of investment capital; ethical, legal, and societal concerns; public understanding, support, and acceptance; and development of a world-class scientific and technical nanotechnology workforce.

This report provides an overview of nanotechnology, the National Nanotechnology Initiative, possible reauthorization of the 21st Century Nanotechnology Research and Development Act of 2003 (P.L. 108-153), and appropriations issues.

[1] In the context of the NNI and nanotechnology, the nanoscale refers to a dimension of 1 to 100 nanometers (see box on this page).

[2] While extensive R&D has been, and continues to be, conducted to understand and harness the properties of individual atoms, this is not the domain of nanotechnology.

# Overview

The economic and societal promise of nanotechnology has led to involvement and investments by governments and companies around the world. In 2000, the United States became the first nation to establish a formal, national initiative to advance nanoscale science, engineering, and technology—the National Nanotechnology Initiative. Since then, the United States has emerged as a global leader in nanotechnology. However, the competition for global leadership is intensifying as foreign investments in nanoscale science, engineering, and technology increase. Other nations have followed the U.S. lead and established their own national nanotechnology programs, each with varying degrees of investment, foci, and support for industrial applications and commercialization. Today, almost every nation that supports research and development (R&D) has a national-level nanotechnology program.

In 2014, Lux Research, an emerging technologies consulting firm, estimated total (public and private) global nanotechnology funding for 2012 to be approximately $18.5 billion.[3] Lux Research had previously estimated that in 2010 corporate R&D had surpassed publicly funded R&D for the first time.[4] Cientifica, a privately held nanotechnology business analysis and consulting firm, estimated global public investments in nanotechnology in 2010 to be approximately $10 billion per year, with cumulative global public investments through 2011 reaching approximately $67.5 billion. In 2011, Cientifica also concluded that the United States had fallen behind both Russia and China in nanotechnology R&D funding on a purchasing power parity (PPP) basis (which takes into account the price of goods and services in each nation), but still led the world in real dollar terms (adjusted on a currency exchange rate basis).[5]

Global investments in nanotechnology have begun to yield economic benefits as products incorporating nanotechnology enter the marketplace. Nano-enabled products are estimated to have produced $731 billion in revenues in 2012.[6] By tapping the unique properties that emerge at the nanoscale, proponents maintain that nanotechnology holds the potential for products that could transform existing industries and create new ones, clean and protect the environment, extend and improve the quality of our lives, and strengthen national security. Most nanotechnology products currently on the market—such as faster computer processors, higher density memory devices, lighter-weight auto parts, more energy-efficient computer and television displays, stain-resistant clothing, antibiotic bandages, cosmetics, and clear sunscreen—are evolutionary in nature, offering incremental improvements in characteristics such as performance, aesthetics, cost, size, and weight.

Evolutionary nanotechnology products, however, represent only a small fraction of what many see as the substantial longer-term economic and societal promise of nanotechnology. A 2014

[3] President's Council of Advisors on Science and Technology, Executive Office of the President, Office of Science and Technology Policy, *Report to the President and Congress on the Fifth Assessment of the National Nanotechnology Initiative*, October 2014.

[4] Working Party on Nanotechnology, Organization for Economic Cooperation and Development, *OECD /NNI International Symposium on Assessing the Economic Impact of Nanotechnology, Background Paper 2: Finance and Investor Models in Nanotechnology,* March 16, 2012, p. 4.

[5] Cientifica, *Global Funding of Nanotechnologies and Its Impact,* July 2011, http://cientifica.eu/blog/wp-content/uploads/downloads/2011/07/Global-Nanotechnology-Funding-Report-2011.pdf.

[6] Lux Research, *Nanotechnology Update: Corporations Up Their Spending as Revenues for Nano-enabled Products Increase*, February 17, 2014.

estimate by Lux Research projects nanotechnology product revenues would reach $4.4 trillion by 2018.[7]

Many nanotechnology advocates—including business executives, scientists, engineers, medical professionals, and venture capitalists—assert that in the longer term, nanotechnology, especially in combination with information technology, biotechnology, and the cognitive sciences, may deliver revolutionary advances, including

- new prevention, detection, and treatment technologies that could reduce substantially death and suffering from cancer and other deadly illnesses;[8]
- new organs to replace damaged or diseased ones;[9]
- contact lenses, skin patches, and glucose-sensing tattoos that monitor diabetics' blood sugar levels and warn when too high or low;[10]
- clothing that protects against toxins and pathogens;[11]
- clean, inexpensive, renewable power through energy creation, storage, and transmission technologies;[12]
- inexpensive, portable water purification systems that provide universal access to safe water;[13]
- energy efficient, low-emission "green" manufacturing systems;[14]
- high-density memory systems capable of storing the entire Library of Congress collection on a device the size of a sugar cube;[15]
- inexpensive, flexible, durable, low-voltage "electronic skin" sensors that allow robots and prosthetic limbs to detect changes in pressure, humidity, and temperature;[16]

[7] Lux Research, "Overhyped Technology Starts to Reach Potential," press release, July 22, 2008, http://www.luxresearchinc.com/press/RELEASE_Nano-SMR_7_22_08.pdf.

[8] National Cancer Institute website. http://nano.cancer.gov/resource_center/tech_backgrounder.asp

[9] Ibid.

[10] Aslan, Kadir; Lakowicz, Joseph R.; and Geddes, Chris D. "Nanogold plasmon resonance-based glucose sensing. Wavelength-ratiometric resonance light scattering," *Analytical Chemistry*, 2005, Vol. 77. National Institute of Diabetes and Digestive and Kidney Disease, National Institutes of Health, Department of Health and Human Services, *Strategic Plan for Pediatric Urology,* February 2006.

[11] Risbud, Aditi. "Fruit of the Nano Loom," *Technology Review*, February 2006.

[12] Nanoscale Science, Engineering, and Technology (NSET) Subcommittee, National Science and Technology Council (NSTC), Executive Office of the President (EOP), *Nanoscience Research for Energy Needs,* December 2004.

[13] Risbud, Aditi. "Cheap Drinking Water from the Ocean," *Technology Review*, June 2006.

[14] Selko, Adrienne. "New Nanotechnology-Based Coatings Are Energy Efficient and Environmentally Sound," *Industry Week*, August 22, 2007. "Tomorrow's Green Nanofactories," *Science Daily*, July 11, 2007.

[15] Interagency Working Group on Nanoscience, Engineering, and Technology, NSTC, EOP, *National Nanotechnology Initiative—Leading to the Next Industrial Revolution,* http://www.ostp.gov/NSTC/html/iwgn/iwgn.fy01budsuppl/nni.pdf.

[16] Meital Segev-Bar, Avigail Landman, and Maayan Nir-Shapira, et al., "Tunable Touch Sensor and Combined Sensing Platform: Toward Nanoparticle-Based Electronic Skin," *ACS Applied Materials and Interfaces*, vol. 5, no. 12 (2013), pp. 5531-5541.

- agricultural technologies that increase crop yield and improve nutritional value, reducing global hunger and malnutrition;[17]
- self-repairing materials;[18]
- powerful, small, inexpensive sensors that can warn of minute levels of toxins and pathogens in air, soil, or water;[19] and
- decontaminated industrial sites through environmental remediation.[20]

While some applications of nanotechnology have proven market-ready, much fundamental research remains ahead, including efforts to advance understanding of nanoscale phenomena; characterize nanoscale materials; understand how to control and manipulate nanoscale particles; develop instrumentation and measurement methods; and understand how nanoscale particles interact with humans, animals, plants, and the environment. In addition, several federal agencies—such as the Departments of Defense, Energy, and Homeland Security—see the potential for nanotechnology to help address mission requirements. Historically, the federal government has played a central role in funding these types of R&D activities.

Though federal nanoscale science, engineering, and technology R&D had been underway for over a decade, the NNI was first initiated as a Presidential technology initiative in 2000.[21] The original participating agencies were the National Science Foundation (NSF), the Department of Defense (DOD), the Department of Energy (DOE), the Department of Commerce's (DOC) National Institute of Standards and Technology (NIST), the National Aeronautics and Space Administration (NASA), and the Department of Health and Human Services' National Institutes of Health (NIH). In 2013, 27 agencies participate in the NNI, including 16 that have received appropriations to conduct and/or fund nanotechnology R&D.[22] Since its first year of funding in FY2001, the NNI's annual appropriations grew four-fold to a peak of $1.9 billion in FY2010. Since then, however, federal nanotechnology funding has declined, falling to an estimated $1.5 billion in FY2014. President Obama has requested $1.5 billion in NNI funding for FY2015.[23]

In 2003, Congress provided a statutory foundation for some of the activities of the NNI through the 21st Century Nanotechnology Research and Development Act of 2003 (P.L. 108-153). The act

[17] U.S. Department of Agriculture, *21st Century Agriculture: A Critical Role for Science and Technology*, June 2003; and *Nanoscale Science and Engineering for Agriculture and Food Systems*: *Draft Report of the National Planning Workshop to the Cooperative State Research, Education, and Extension Service of the U.S. Department of Agriculture*, July 2003.

[18] NSET Subcommittee, NSTC, EOP, *Nanotechnology in Space Exploration*, August 2004, http://www.nano.gov/nni_space_exploration_rpt.pdf.

[19] NSET Subcommittee, NSTC, EOP, *Nanotechnology and the Environment*, May 2003, http://www.nano.gov/NNI_Nanotechnology_and_the_Environment.pdf.

[20] U.S. Environmental Protection Agency, *Proceedings of the U.S. Environmental Protection Agency Workshop on Nanotechnology for Site Remediation,* October 2005.

[21] The White House, "National Nanotechnology Initiative: Leading to the Next Industrial Revolution," press release, January 21, 2000, http://clinton4.nara.gov/WH/New/html/20000121_4.html; and "Steering the technology that will redefine life as we know it," *Industrial Biotechnology*, Vol. 1, No. 3, Fall 2005, http://www.nsf.gov/crssprgm/nano/reports/mcr_ind_biotech_interview.pdf.

[22] Fifteen agencies received funding in FY2013 for nanotechnology R&D; the Department of Justice has not received nanotechnology R&D funding since FY2010.

[23] NSET Subcommittee, NSTC, EOP, *The National Nanotechnology Initiative: Supplement to the President's FY2013 Budget*, March 2014.

established a National Nanotechnology Program (NNP) and provided authorizations for a subset of the NNI agencies, namely the NSF, DOE, NASA, NIST, and Environmental Protection Agency (EPA).[24] The act, however, did not address the participation of several agencies that fund nanotechnology R&D under the NNI, including DOD, NIH, and the Department of Homeland Security (DHS). Nevertheless, coordination of nanotechnology R&D activities across all NNI funding agencies continues under the National Science and Technology Council's (NSTC's) Nanoscale Science, Engineering, and Technology (NSET) Subcommittee.[25] According to the NSET Subcommittee's 2004 NNI Strategic Plan, "For continuity and to capture this broader participation, the coordinated federal activities as a whole will continue to be referred to as the National Nanotechnology Initiative." Accordingly, the functions and activities established under the act are incorporated into the executive branch's implementation of the NNI.

The thrust of the NNI has primarily been the development of fundamental scientific knowledge through basic research. Investments at mission agencies, such as DOD, have supported nanotechnology applications development for which they are a primary customer. Other investments have supported infrastructural technologies. For example, NIST has contributed to developing tools and standards that enable measurement and control of matter at the nanoscale, thereby supporting the conduct of R&D and the ability to manufacture nanoscale materials and products. As understanding of nanotechnology has matured, the NNI has worked with a variety of industry organizations to facilitate the movement of research results from the laboratory bench to the marketplace in fields as disparate as semiconductors, energy, concrete, and forest products.

The NNI agencies also have sought to address research needs and regulatory issues related to environmental, health, and safety, as well as issues such as public understanding and workforce education and training. The NNI agencies actively engage in a variety of international fora, such as the Organization for Economic Cooperation and Development (OECD) and the International Standards Organization (ISO), to cooperatively address nanotechnology issues related to EHS, metrology[26] and standards, nomenclature, and nanoscale materials characterization.

Maintaining U.S. leadership poses a variety of technical, economic, and policy challenges, including

- safeguarding the environment and ensuring human health and safety;
- creating the standards, reference materials, nomenclature, methods, and tools for metrology to enable the manufacturing of nanoscale materials and products;
- developing a world-class scientific and technical nanotechnology workforce;
- translating research results into products, including effective technology transfer to the private sector;
- understanding public perceptions and attitudes and fostering public understanding;

[24] While many provisions of this act have no sunset provision, FY2008 was the last year of agency authorizations included in the act.

[25] Prior to P.L. 108-153, the Bob Stump Defense Authorization Act for Fiscal Year 2003 (P.L. 107-314) required DOD to "provide for interagency cooperation and collaboration on nanoscale research and development." The NSET Subcommittee is a subcommittee of the NSTC Committee on Technology.

[26] Metrology is the science of measurement, including the equipment and processes used to produce a measurement.

- addressing ethical, legal, and societal implications;
- protecting intellectual property;
- securing investment capital for early-stage research, development, and commercialization; and
- fostering and facilitating international cooperation and coordination.

Proponents of the NNI assert that nanotechnology is one of the most important emerging and enabling technologies[27] and that U.S. competitiveness, technological leadership, national security, and societal interests require an aggressive approach to the development and commercialization of nanotechnology. Critics of the NNI hold a variety of competing views, asserting that government is not doing enough, is doing too much, or is moving too quickly.

Some in industry have criticized the NNI for being overly focused on basic research and not being aggressive enough in moving NNI-funded R&D out of government and university laboratories and into industry. Others in industry have criticized the federal government for not providing mechanisms to help advance nanotechnology R&D to the point where it becomes economically viable for venture capitalists, corporations, and other investors to create products and bring them to market. Some refer to this gap as the "valley of death."[28] Still others in industry have criticized the NNI for not adequately supporting the development of metrology, standards, equipment, and processes necessary to manufacture nanotechnology materials, products, and systems at a commercial scale.

Conversely, supporters of industry-driven market investments contend that extensive government support for nanotechnology may supplant the judgment of the marketplace by picking "winners and losers" in technological development. For example, the size and directions of the NNI investments may encourage industry to follow the government's lead rather than independently selecting R&D directions itself or, alternatively, may result in the promotion of a less effective technology path over a more effective one. These supporters also assert that federal government funding of scientific research is often wasteful, driven by political considerations and not scientific merit.[29]

Some non-governmental organizations (NGOs) are critical of nanotechnology for its potential adverse impacts on human health and safety and on the environment. They assert that the government is pushing ahead too quickly in developing nanotechnology and encouraging its commercialization and use without adequately investing in research focused on understanding and mitigating negative EHS implications.[30] They argue that the very characteristics that make

[27] The Department of Commerce has characterized emerging and enabling technologies as those that "offer a wide breadth of potential application and form an important technical basis for future commercial applications." (ATP Rule, 15 C.F.R. Part 295).

[28] The term "valley of death" is used by business executives, economists, and venture capitalists to describe the development gap that often exists between a laboratory discovery and the market's willingness to invest to advance the discovery to a final commercial product. This gap occurs due to a variety of issues, such as technical risk, market uncertainty, and likelihood of obtaining an adequate return on investment.

[29] Crews, Clyde Wayne Jr., "Washington's Big Little Pork Barrel: Nanotechnology," Cato Institute website, May 29, 2003.

[30] Testimony of Andrew Maynard, Chief Science Advisor, Project on Emerging Nanotechnologies, Woodrow Wilson International Center for Scholars, "Research on Environmental and Safety Impacts of Nanotechnology: Current Status of Planning and Implementation under the National Nanotechnology Initiative," hearing, Subcommittee on Research (continued...)

nanotechnology promising also present significant potential risks to human health and safety and the environment. Some of these critics argue for application of the "precautionary principle," which holds that regulatory action may be required to control potentially hazardous substances even before a causal link has been established by scientific evidence.[31] At least one NGO has called for a moratorium on nanotechnology R&D and new commercial products incorporating synthetic nanoparticles.[32]

# National Nanotechnology Initiative

The National Nanotechnology Initiative is an interagency program that coordinates federal nanoscale science, engineering, and technology R&D activities and related efforts among participating agencies.

## Vision and Goals

The National Science and Technology Council has stated the following vision for the NNI:

> The vision of the NNI is a future in which the ability to understand and control matter at the nanoscale leads to a revolution in technology and industry that benefits society. The NNI expedites the discovery, development, and deployment of nanoscale science, engineering, and technology to serve the public good, through a program of coordinated research and development aligned with the missions of the participating agencies.[33]

To achieve its vision, the NNI has established four goals:

- advance a world-class R&D program;
- foster the transfer of new technologies into products for commercial and public benefit;
- develop and sustain educational resources, a skilled workforce, and a dynamic infrastructure and toolset to advance nanotechnology; and
- support responsible development of nanotechnology.[34]

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(...continued)

and Science Education, House Committee on Science and Technology, October 31, 2007.

[31] "NGOs urge precautionary principle in use of nanomaterials," EurActiv.com, June 14, 2007. http://www.euractiv.com/en/environment/ngos-urge-precautionary-principle-use-nanomaterials/article-164619, Sass, Jennifer. "Nanotechnology and the Precautionary Principle," presentation, Natural Resources Defense Council, 2006. http://docs.nrdc.org/health/hea_06121402a.pdf, The precautionary principle has been used in other countries on some issues. For example, the Biosafety Protocol to the 1992 Convention on Biological Diversity incorporates provisions applying the precautionary principle to the safe handling, transfer, and trade of genetically modified organisms. For further information, see CRS Report RL30594, *Biosafety Protocol for Genetically Modified Organisms: Overview*, by Alejandro E. Segarra and Susan R. Fletcher.

[32] ETC Group, "No Small Matter II: The Case for a Global Moratorium—Size Matters!," Occasional Paper Series, April 2003, http://www.etcgroup.org/upload/publication/pdf_file/165.

[33] NSET Subcommittee, NSTC, EOP, *The National Nanotechnology Initiative Strategic Plan,* February 2014, http://nano.gov/sites/default/files/pub_resource/2014_nni_strategic_plan.pdf.

[34] Ibid.

## History

Attempts to coordinate federal nanoscale R&D began in November 1996, as staff members from several agencies met regularly to discuss their plans and programs in nanoscale science and technology. This group continued informally until September 1998, when it was designated as the Interagency Working Group on Nanotechnology (IWGN) under the NSTC. In August 1999, IWGN completed its first draft of a plan for an initiative in nanoscale science and technology, which was subsequently approved by the President's Council of Advisors on Science and Technology (PCAST) and the White House Office of Science and Technology Policy (OSTP).[35]

In his FY2001 budget submission to Congress, then-President Clinton raised nanotechnology-related research to the level of a federal initiative, officially referring to it as the National Nanotechnology Initiative.[36]

## Legislative Approach

Congress has played a central role in the National Nanotechnology Initiative, providing appropriations for the conduct of nanoscale science, engineering, and technology research; establishing programs; and creating a legislative foundation for the activities of the NNI.

Congressional funding for the NNI is provided through appropriations to each of the NNI-participating agencies. The NNI has no centralized funding. The overall NNI budget is calculated by aggregating the nanotechnology budgets for each of the federal agencies that conduct or provide funding for nanoscale R&D.

In FY2001, the first year of NNI funding, Congress provided $464 million to eight agencies for nanoscale R&D.[37] The NNI has continued to receive support from both Congress and the White House. Both the number of agencies participating in the NNI and the size of the federal investment have grown. Currently 27 agencies participate in the NNI, 16 of which have received appropriated funds for nanotechnology R&D.[38] Total NNI funding in FY2013 is estimated at approximately $1.6 billion. The original six agencies identified at the launch of the NNI[39] still account for the vast majority of NNI funding (approximately 95% in FY2013).

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[35] National Nanotechnology Initiative website, http://www.nano.gov/html/about/history.html.

[36] The White House, "National Nanotechnology Initiative: Leading to the Next Industrial Revolution," press release, January 21, 2000. http://clinton4.nara.gov/WH/New/html/20000121_4.html; and National Nanotechnology Initiative website, http://www.nano.gov/html/about/history.html.

[37] In its January 21, 2001 press release, "National Nanotechnology Initiative: Leading to the Next Industrial Revolution," announcing the establishment of the NNI, the White House identified only six participating agencies—NSF, DOD, DOE, NIST, NASA, and NIH. Subsequently, EPA and DOJ reported nanotechnology R&D funding in FY2001, bringing the total number of agencies funding nanotechnology R&D in FY2001 to eight.

[38] NNI participants include agencies that either conduct or provide funding for nanotechnology R&D, as well as agencies with missions that may affect the development, commercialization, and use of nanotechnology. For example, in the latter case, the Food and Drug Administration may regulate (or not regulate) nanotechnology products, the U.S. Patent and Trademark Office's (USPTO) treatment of nanotechnology-related patents may affect the value of the underlying intellectual property, and the execution of the missions of the Departments of Education and Labor could affect the preparedness of the U.S. workforce for emerging nanotechnology jobs. Some nanotechnology R&D agencies may also have non-R&D missions related to nanotechnology. For example, EPA conducts and funds R&D but also has a regulatory mission that could affect nanotechnology research, development, production, use, and/or disposal.

[39] The original six agencies identified at the launch of the NNI were the Department of Defense, Department of Energy, (continued...)

## 21st Century Nanotechnology Research and Development Act of 2003

Congress codified and further defined some of the NNI's activities in the 21st Century Nanotechnology Research and Development Act of 2003 which was passed by Congress in November 2003, and signed into law (P.L. 108-153) by President Bush on December 3, 2003.[40] The legislation received strong bipartisan support in both the House of Representatives, which passed the bill on a recorded vote of 405-19, and in the Senate, which passed the bill by unanimous consent.

Though this act is often referred to as the enabling legislation for the National Nanotechnology Initiative, the act actually establishes a National Nanotechnology Program (NNP). The act provides authorizations for five NNI agencies—the National Science Foundation, Department of Energy, NASA, National Institute of Standards and Technology, and Environmental Protection Agency—but not for the Department of Defense, National Institutes of Health, Department of Homeland Security,[41] or other NNI research agencies that collectively accounted for 46% of NNI funding in FY2003.

The act created the NNP for the purposes of establishing the goals, priorities, and metrics for evaluation of federal nanotechnology research, development, and other activities; investing in federal R&D programs in nanotechnology and related sciences to achieve those goals; and providing for interagency coordination of federal nanotechnology research, development, and other activities undertaken pursuant to the NNP.

Key provisions of the act include

- authorizing appropriations for the nanotechnology-related activities of the NSF, DOE, NASA, NIST, and EPA for fiscal years 2005 through 2008, totaling $3.679 billion for the four year period;
- establishing a National Nanotechnology Coordination Office, with a director and full time staff to provide administrative support to the NSTC;
- establishing a National Nanotechnology Advisory Panel (NNAP) to advise the President and the NSTC on matters relating to the NNP;[42]
- establishing a triennial review of the NNP by the National Research Council of the National Academy of Sciences;

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National Institute of Standards and Technology (Department of Commerce), National Science Foundation, National Aeronautics and Space Administration, and National Institutes of Health (DHHS). The White House, "National Nanotechnology Initiative: Leading to the Next Industrial Revolution," press release, January 21, 2000. http://clinton4.nara.gov/WH/New/html/20000121_4.html; and National Nanotechnology Initiative website. http://www.nano.gov/html/about/history.html.

[40] U.S. Congress. 2003. 21st Century Nanotechnology Research and Development Act. P.L. 108-153. 15 U.S.C. 7501. 108 Cong., December 3.

[41] FY2003 funding attributed to DHS for the purpose of this calculation is based on nanotechnology R&D appropriations received by the Department of Transportation's Transportation Security Administration (TSA). TSA was transferred to DHS in the Homeland Security Act of 2002 (P.L. 107-296) which was enacted after the start of FY2003.

[42] Executive Order 13539 designates the President's Council of Advisors on Science and Technology (PCAST) as the National Nanotechnology Advisory Panel (NNAP), http://www.gpo.gov/fdsys/pkg/FR-2010-04-27/pdf/2010-9796.pdf.

- directing the NSTC to oversee the planning, management, and coordination of the program, including the development of a triennial strategic plan;
- directing the Department of Commerce's National Institute of Standards and Technology to establish a program to conduct basic research on issues related to the development and manufacture of nanotechnology, and to use the Manufacturing Extension Partnership program to ensure results reach small- and medium-sized manufacturing companies;
- directing the Secretary of Commerce to use the National Technical Information Service to establish a clearinghouse of information related to commercialization of nanotechnology research;
- directing the Secretary of Energy to establish a program to support consortia to conduct interdisciplinary nanotechnology R&D designed to integrate newly developed nanotechnology and microfluidic tools with systems biology and molecular imaging;
- directing the Secretary of Energy to carry out projects to develop, plan, construct, acquire, operate, or support special equipment, instrumentation, or facilities for investigators conducting nanotechnology R&D; and
- directing the establishment of two centers, on a merit-reviewed and competitive basis: (1) the American Nanotechnology Preparedness Center, to conduct, coordinate, collect, and disseminate studies on the societal, ethical, environmental, educational, legal, and workforce implications of nanotechnology; and to identify anticipated issues related to the responsible research, development, and application of nanotechnology, as well as provide recommendations for preventing or addressing such issues; and (2) the Center for Nanomaterials Manufacturing, to encourage, conduct, coordinate, commission, collect, and disseminate research on new manufacturing technologies for materials, devices, and systems with new combinations of characteristics, such as, but not limited to, strength, toughness, density, conductivity, flame resistance, and membrane separation characteristics; and to develop mechanisms to transfer such manufacturing technologies to U.S. industries.

While the act establishes a National Nanotechnology Program, the executive branch continues its broader effort under the NNI framework and name. According to the NNI's 2004 Strategic Plan:

> Many of the activities outlined in the Act were already in progress as part of the NNI. Moreover, the ongoing management of the initiative involves considerable input from Federal agencies that are not named specifically in the Act.... For continuity, and to capture this broader participation, the coordinated Federal activities as a whole will continue to be referred to as the National Nanotechnology Initiative.[43]

[43] NSET Subcommittee, NSTC, EOP, *The National Nanotechnology Initiative Strategic Plan*, December 2004, http://www.nano.gov/NNI_Strategic_Plan_2004.pdf.

## Reauthorization Efforts

The 21st Century Nanotechnology Research and Development Act provided a legislative foundation for some of the activities of the NNI, authorized agency funding levels through FY2008, and sought to address challenges associated with the development and commercialization of nanotechnology. While many provisions of this act have no sunset provision, FY2008 was the last year of agency authorizations included in the act.

Legislation to amend and reauthorize the act was introduced in the House in both the 113th Congress, 111th Congress, and 110th Congress. No comprehensive reauthorization legislation was introduced in 112th Congress.

In the 113th Congress, bills were introduced in the House and Senate that sought to amend the 21st Century Nanotechnology Research and Development Act. In the House bill, the National Nanotechnology Initiative Amendments Act of 2014 was incorporated as part of H.R. 4159, the America COMPETES Reauthorization Act of 2014, which was referred to two committees and multiple subcommittees. No further action was taken on the bill. In the Senate, the National Nanotechnology Initiative Amendments Act of 2014 was incorporated as part of S. 2757, the America COMPETES Reauthorization Act of 2014. S. 2757 was referred to the Senate Committee on Commerce, Science, and Transportation and no further action was taken.

Several earlier efforts were made to amend and/or reauthorize provisions of the 21st Century Nanotechnology Research and Development Act, including:

- On May 7, 2010, the House Committee on Science and Technology reported the America COMPETES Reauthorization Act of 2010 (H.R. 5116, 111th Congress) which included, as Title I, Subtitle A, the "National Nanotechnology Initiative Amendments Act of 2010." Provisions of this subtitle were nearly identical to the provisions of H.R. 554 (111th Congress). This title was removed from the bill prior to its enactment.
- H.R. 820 (111th Congress), the Nanotechnology Advancement and New Opportunities Act, also would have amended P.L. 108-153. The provisions of H.R. 820 covered a variety of jurisdictions, thus the bill was assigned to multiple House committees. No further action was taken.
- S. 1482 (111th Congress), the National Nanotechnology Initiative Amendments Act of 2009, was introduced in the Senate and referred to the Committee on Commerce, Science, and Transportation. No further action was taken.
- H.R. 554 (111th Congress), the National Nanotechnology Initiative Amendments Act of 2009, contained essentially the same provisions as H.R. 5940 (110th Congress). In February 2009, the House passed the bill by voice vote under a suspension of the rules. The Senate did not act on H.R. 554.
- H.R. 5940 (110th Congress) and S. 3274 (110th Congress) were both titled the National Nanotechnology Initiative Amendments Act of 2008. The House passed H.R. 5940 by a vote of 407-6; the Senate did not act on S. 3274.

For additional information, see **Appendix A**, "Selected Nanotechnology Legislation in the 113th, 112th, and 111th Congresses."

# Structure

## Nanoscale Science, Engineering, and Technology (NSET) Subcommittee

The NNI is coordinated within the White House through the NSTC, the Cabinet-level council by which the President coordinates science, space, and technology policies across the federal government. Operationally, NNI coordination is accomplished through the Nanoscale Science, Engineering, and Technology Subcommittee of the NSTC's Committee on Technology (CT). The NSET Subcommittee also has an informal reporting relationship to the NSTC's Committee on Science (CS). The NSET Subcommittee is led by an agency co-chair, currently from NIST, and an OSTP co-chair. The NSET Subcommittee is comprised of representatives from 27 federal entities (including 16 that have funded, over the course of the NNI, nanotechnology R&D), OSTP and the Office of Management and Budget.[44]

The NSET Subcommittee has two working groups—Nanotechnology Environmental and Health Implications (NEHI) and Nanomanufacturing, Industry Liaison, and Innovation (NILI). In addition, coordinators have been established for four issue areas: global issues; standards development; environmental, health, and safety research; and education, engagement, and societal dimensions.[45] Two previously established working groups—Global Issues in Nanotechnology and Nanotechnology Public Engagement and Communications—were eliminated.

### *Nanotechnology Environmental and Health Implications*

The Nanotechnology Environmental and Health Implications working group was chartered to provide for exchange of information among agencies that support research and those responsible for regulations and guidelines related to nanotechnology products; to facilitate identification, prioritization, and implementation of research and other activities required for the responsible research, development, utilization, and oversight of nanotechnology; and to promote communication of information related to research on environmental and health implications of nanotechnology to other government agencies and non-government parties. To this end, the NEHI working group seeks to identify and prioritize EHS research needs related to nanotechnology. Sixteen NNI agencies (as well as the National Nanotechnology Coordination Office (NNCO), OSTP, and OMB) participate in the NEHI working group, including agencies that fund safety-

[44] The agencies that participate in the NSET Subcommittee comprise the NNI. NSET Subcommittee members include Forest Service, USDA; National Institute of Food and Agriculture, USDA; Agricultural Research Service, USDA; Bureau of Industry and Security, DOC; Consumer Product Safety Commission; DOD; Department of Education; DOE; DHS; Department of Justice; Department of Labor; Department of State; Department of Transportation; Department of the Treasury; Director of National Intelligence; Economic Development Administration, DOC; EPA; Food and Drug Administration, HHS; U.S. International Trade Commission; NASA; NIH, Department of Health and Human Services (HHS); NIOSH, Centers for Disease Control and Prevention, HHS; NIST, DOC; NSF; Nuclear Regulatory Commission; U.S. Geological Survey, Department of the Interior; and U.S. Patent and Trademark Office, DOC. The Department of Commerce's Technology Administration was a participating agency in the NNI until its elimination in August 2007 under the America COMPETES Act (P.L. 110-69). Two Executive Office of the President organizations also participate on the NSET Subcommittee, the Office of Science and Technology Policy and the Office of Management and Budget.

[45] NSET Subcommittee, NSTC, EOP, *The National Nanotechnology Initiative: Research and Development Leading to a Revolution in Technology and Industry-Supplement to the President's FY2008 Budget*, July 2007, http://www.nano.gov/NNI_08Budget.pdf.

related nanotechnology research and/or have regulatory authorities to guide the safe use of nanomaterials.[46]

### *Nanomanufacturing, Industry Liaison, and Innovation*

The Nanomanufacturing, Industry Liaison, and Innovation (NILI) working group was chartered to enhance collaboration and information sharing between U.S. industry and government on nanotechnology-related activities to advance and accelerate the creation of new products and manufacturing processes derived from discovery at the nanoscale. It also facilitates federal, regional, state, and local nanotechnology R&D and commercialization activities. In addition, the NILI working group is to create innovative methods for transferring federally funded technology to industry. The NILI working group has facilitated collaborations between the NNI and the semiconductor/electronics industry, chemical industry, forest products industry, and the Industrial Research Institute.[47]

## National Nanotechnology Coordination Office

The National Nanotechnology Coordination Office provides administrative and technical support to the NSET Subcommittee. Initially established in 2001 through a memorandum of understanding among the NNI participating agencies, the NNCO was authorized by the 21st Century Nanotechnology Research and Development Act of 2003 (P.L. 108-153). The NNCO was charged under the act with providing technical and administrative support to the NSTC and NNAP; serving as the point of contact for information on federal nanotechnology activities for the exchange of technical and programmatic information among stakeholders; conducting public outreach; and promoting access to and early application of NNP technologies, innovation, and expertise.

In addition, the NNCO serves as a liaison to academia, industry, professional societies, foreign organizations, and others, facilitating the exchange of technical and programmatic information. The NNCO also coordinates preparation and publication of NNI interagency planning, budget, and assessment documents, and maintains the NNI website, http://www.nano.gov.

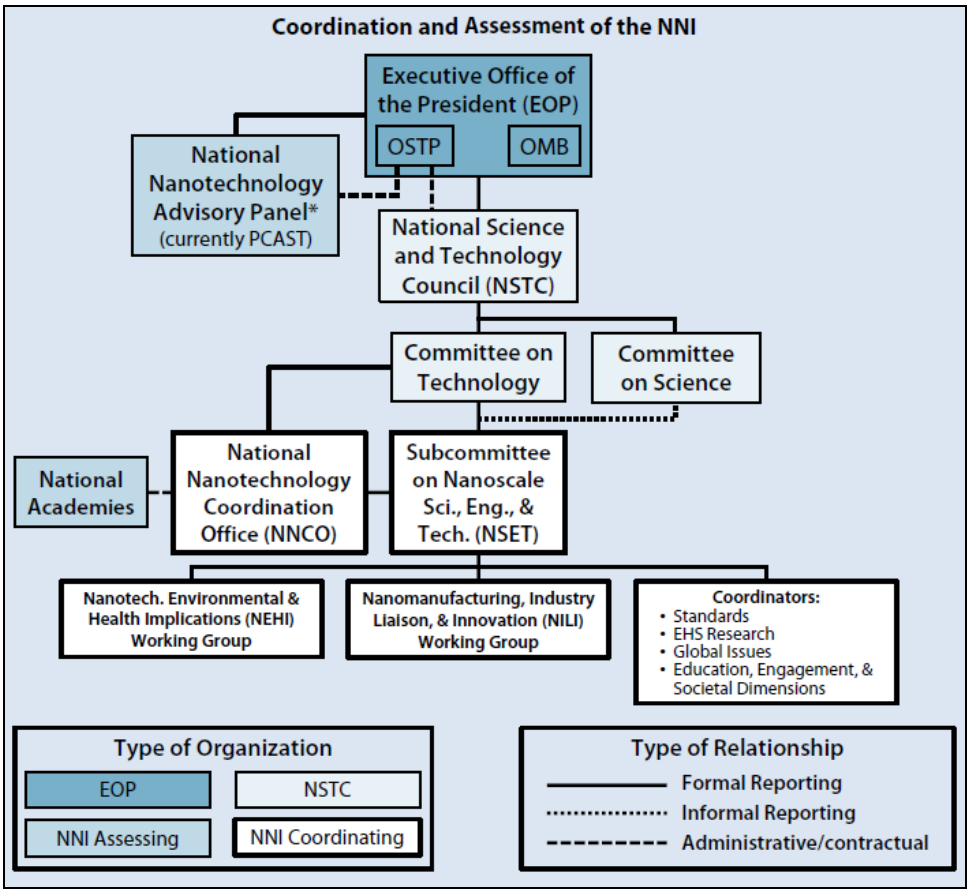
The act authorizes the work of the NNCO to be funded by contributions from NSET Subcommittee member agencies. According to the NNCO, funding is provided through a memorandum of understanding signed by eight NNI agencies. In principle, each agency contributes to the NNCO budget in proportion to its share of the President's total nanotechnology budget request for the signatory agencies. However, two of the signatories, EPA and DOT, had sufficiently small enough nanotechnology budgets in the early years of the NNI that they were not expected to contribute. EPA now contributes to funding the NNCO. Total NNCO funding from the agencies in FY2013 was $3.0 million.[48] Five agencies—NSF, NIH, DOD, DOE, and DOC—accounted for approximately 95% of this funding. This funding supports NNCO staff and activities, as well as funding for the triennial review of the NNI by the National Research Council.

[46] NNI website, http://nano.gov/nehi.

[47] The Industrial Research Institute is an association of companies and federally funded laboratories with the mission of improving R&D capabilities through the development and dissemination of best practices.

[48] OSTP/OMB, EOP, *FY 2013 Interagency Funding For Activities of the National Science And Technology Council.*

**Figure 1. Organizations With a Role in the National Nanotechnology Initiative and Their Relationships**




**Source:** Reproduced from *The National Nanotechnology Initiative Strategic Plan*, Nanoscale, Science, Engineering, and Technology Subcommittee, National Science and Technology Council, The White House, February 2014.

**Note:**

* Executive Order 13539 designates the President's Council of Advisors on Science and Technology (PCAST) as the National Nanotechnology Advisory Panel (NNAP), http://www.gpo.gov/fdsys/pkg/FR-2010-04-27/pdf/2010-9796.pdf.

# Funding

The NNI supports fundamental and applied research on nanotechnology by funding research, creating multidisciplinary centers of excellence, and developing key research infrastructure. It also supports activities aimed at addressing the societal implications of nanotechnology, including ethical, legal, human and environmental health, and workforce issues.

This section provides information on NNI funding from two perspectives: organizationally by agency and functionally by program component area.

## Agency Funding

The NNI budget is an aggregation of the nanotechnology components of the individual budgets of NNI-participating agencies. The NNI budget is not a single, centralized source of funds that is allocated to individual agencies. In fact, agency nanotechnology budgets are developed internally as part of each agency's overall budget development process. These budgets are subjected to review, revision, and approval by the Office of Management and Budget and become part of the President's annual budget submission to Congress. The NNI budget is then calculated by aggregating the nanotechnology components of the appropriations provided by Congress to each federal agency.

For FY2014, NNI R&D funding totaled an estimated $1.538 billion, a $12.7 million (0.8%) decrease from FY2013. The overall increase was driven primarily by reductions in the R&D budgets of NIH (down $17.3 million, 3.8%), DOE (down $10.9 million, 3.5%), and NSF (down $10.4 million, 2.5%), and offset, in part, by increases at DHS (up $10 million, 71.4%), NIST (up $6.4 million, 7.0%), and DOD (up $5.8 million, 3.4%). The chronology of NNI funding by agency is detailed in **Table 1**.

President Obama has requested $1.537 billion in funding for the NNI in FY2015, essentially the same as in FY2014. In general, increases in funding for DOE and DHS would be offset by decreases at DOD, NIST, and NASA. The FY2015 NNI budget request would support a broad range of programs among 15 agencies. Five agencies accounted for 93% of NNI funding in FY2014:[49]

- HHS, primarily NIH, (28.7%), which emphasizes nanotechnology-based biomedical advances occurring at the intersection of biology and the physical sciences;
- NSF (26.7%), which supports fundamental nanotechnology research across science and engineering disciplines;
- DOE (19.7%), which supports nanotechnology research providing a basis for new and improved energy efficiency, production, storage, and transmission technologies;
- DOD (11.4%), whose investments in nanotechnology are aimed at addressing the department's national security mission; and
- NIST (6.4%), which focuses on research in instrumentation, measurement, standards, characterization, and nanomanufacturing.

Other agencies investing in mission-related nanotechnology R&D are: DHS; NASA; EPA; the National Institute of Food and Agriculture (NIFA), Forest Service, and Agricultural Research Service (ARS) at the Department of Agriculture (USDA); the National Institute of Occupational Safety and Health (NIOSH) and Food and Drug Administration (FDA) at the Department of Health and Human Services (HHS); DHS; Department of Transportation's (DOT) Federal Highway Administration (FHWA); and the Consumer Product Safety Commission (CPSC).

[49] Based on FY2014 estimated funding levels.

## Table 1. NNI Funding, by Agency: FY2001-FY2014 and FY2015 Request

(in millions of current dollars)

| Agency | FY 2001 Actual | FY 2002 Actual | FY 2003 Actual | FY 2004 Actual | FY 2005 Actual | FY 2006 Actual | FY 2007 Actual | FY 2008 Actual | FY 2009 Actual | ARRA (P.L. 111-5)[a] | FY 2010 Actual | FY 2011 Actual | FY 2012 Est. | FY 2013 Actual | FY 2014 Est.[b] | FY2015 Request |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Department of Energy[c] | 88 | 89 | 134 | 202 | 208 | 231 | 236 | 245 | 332.6 | 293.2 | 373.8 | 346.2 | 313.8 | 314.2 | 303.3 | 343.1 |
| National Science Foundation | 150 | 204 | 221 | 256 | 335 | 360 | 389 | 409 | 408.6 | 101.2 | 428.7 | 485.1 | 466.3 | 421.0 | 410.6 | 412.4 |
| National Institutes of Health (HHS) | 40 | 59 | 78 | 106 | 165 | 192 | 215 | 305 | 342.8 | 73.4 | 456.8 | 408.6 | 456.0 | 458.8 | 441.5 | 441.5 |
| Department of Defense[d] | 125 | 224 | 220 | 291 | 352 | 424 | 450 | 460 | 459.0 | | 439.6 | 425.3 | 426.1 | 170.1 | 175.9 | 144.0 |
| Nat'l Inst. of Standards and Tech. (DOC) | 33 | 77 | 64 | 77 | 79 | 78 | 88 | 86 | 93.4 | 43.4 | 114.7 | 95.9 | 95.4 | 91.4 | 97.8 | 82.6 |
| NASA | 22 | 35 | 36 | 47 | 45 | 50 | 20 | 17 | 13.7 | | 19.7 | 17.0 | 18.6 | 16.4 | 17.9 | 13.7 |
| Environmental Protection Agency | 5 | 6 | 5 | 5 | 7 | 5 | 8 | 12 | 11.6 | | 17.7 | 17.4 | 17.5 | 14.6 | 15.5 | 16.8 |
| Food and Drug Administration (HHS) | | | | | | | | | 6.5 | | 7.3 | 9.9 | 13.6 | 16.1 | 17.0 | 17.0 |
| Nat'l Inst. for Occ. Safety and Health (HHS) | | | | | 3 | 4 | 7 | 7 | 6.7 | | 8.5 | 10.0 | 10.0 | 10.5 | 11.0 | 11.1 |
| Nat'l Inst. of Food and Agriculture (USDA)[e] | | | 1 | 2 | 3 | 4 | 4 | 6 | 9.9 | | 13.2 | 10.0 | 11.3 | 12.5 | 13.1 | 12.8 |
| Department of Homeland Security | | 2 | 1 | 1 | 1 | 2 | 2 | 3 | 9.1 | | 21.9 | 9.0 | 18.7 | 14.0 | 24.0 | 32.4 |
| Forest Service (USDA) | | | | | | 2 | 3 | 5 | 5.4 | | 7.1 | 10.0 | 5.0 | 5.0 | 4.0 | 4.0 |
| Agricultural Research Service (USDA) | | | | | | | | | | | | | 2.0 | 2.0 | 2.0 | 2.0 |
| Federal Highway Administration (DOT) | | | | | | 1 | 1 | 1 | 0.9 | | 3.2 | 1.0 | 1.0 | 2.4 | 2.0 | 1.5 |
| Consumer Product Safety Commission | | | | | | | | | 0.2 | | 0.5 | 1.8 | 2.0 | 1.3 | 2.0 | 2.0 |
| Department of Justice | 1 | 1 | 1 | 2 | 2 | <1 | 2 | 0 | 1.2 | | 0.2 | | | | | |
| **TOTAL**[f] | 464 | 697 | 760 | 989 | 1,200 | 1,351 | 1,425 | 1,554 | 1,701.6 | 511.3 | 1,912.8 | 1,847.3 | 1,857.3 | 1,550.2 | 1,537.5 | 1,536.9 |

**Sources:** NNI website, http://www.nano.gov; NSET Subcommittee, NSTC, EOP, *The National Nanotechnology Initiative, Supplement to the President's FY2015 Budget,* March 2014.

**Notes:**

a. Funding figures for nanotechnology-related R&D under the ARRA are preliminary estimates.

b. 2014 numbers are based on 2014 enacted levels, and may shift as operating plans are finalized.

c. Funding levels for DOE include the combined budgets of the Office of Science, the Office of Energy Efficiency and Renewable Energy (EERE), the Office of Fossil Energy, and the Advanced Research Projects Agency for Energy (ARPA-E).

d. According to NSTC, the DOD budgets shown above include congressionally directed funding of approximately $76 million in FY2006, $63 million in FY2007, $117 million in FY2009, and $75 million in FY2010. According to NSTC, the 2008 DOD estimate "includes many earmarks that are outside the NNI plan."

e. Formerly, the USDA Cooperative State Research, Education, and Extension Service (CSREES).

f. Totals may differ from the sum of the components due to rounding.

## Program Component Area Funding

The 21st Century Nanotechnology R&D Act of 2003 called for the NSET Subcommittee to develop categories of investment called Program Component Areas (PCA) to provide a means by which Congress and the executive branch can be informed of and direct the relative investments in these areas. The PCAs are categories of investments that cut across the needs and interests of individual agencies and contribute to the achievement of one or more of the NNI's goals.

The 2004 NNI *Strategic Plan* identified seven PCAs. The 2007 NNI *Strategic Plan* split the seventh PCA, Societal Dimensions, into two PCAs: Environment, Health, and Safety; and Education and Societal Dimensions. In 2014, the NSET Subcommittee revised its taxonomy for PCAs in order "to accommodate the maturation of the Initiative, the enhanced emphasis on applications, and the greater participation by agencies and communities that are not focused primarily on R&D."[50] The revision reduces the number of PCAs from eight to five. Of particular note is the addition of a PCA to identify funding devoted to the Nanotechnology Signature Initiatives (NSIs) with a breakout of funding provided for each NSI. According to the NSET Subcommittee "the new PCAs are more broadly strategic, fully inclusive, and consistent with Federal research categories, while correlating well with the NNI goals and high-level objectives."[51]

A description of the new PCAs and their current funding is provided below. A chronology of NNI funding by PCA is provided in **Table 2** using the new PCA structure for FY2013 to FY2015 (request) and in **Table 3** using the previous PCA structure from FY2006-FY2012.[52]

### *Nanotechnology Signature Initiatives*

The NNI's Nanotechnology Signature Initiatives (NSIs) are multi-agency, cross-sector collaborations designed to accelerate innovation in targeted areas of national priority. According to the NSET Subcommittee:

> NSIs serve to spotlight topical areas that exhibit particular promise, existing effort, and significant opportunity, and that bridge across multiple Federal agencies. They are intended to be dynamic, with topical areas rotating and evolving over time. This category includes foundational research and nanotechnology-enabled applications, devices, and systems within each NSI, as appropriate. Instrumentation that is specifically developed in support of a confined topical area covered by one of the NSIs is included here, but otherwise, the development or acquisition of more broadly applicable instrumentation (as well as resources devoted to facilities) falls under the separate PCA on Research Infrastructure and Instrumentation. Most research on Environment, Health, and Safety falls within the separate PCA ... but activities directly pertinent to specific NSIs are reported [under the NSI PCA].[53]

[50] NSET Subcommittee, NSTC, EOP, *The National Nanotechnology Initiative Strategic Plan,* February 2014, http://nano.gov/sites/default/files/pub_resource/2014_nni_strategic_plan.pdf.

[51] NSET Subcommittee, NSTC, EOP, *The National Nanotechnology Initiative: Supplement to the President's FY2015 Budget*, March 2014, http://nano.gov/sites/default/files/pub_resource/nni_fy15_budget_supplement.pdf.

[52] A description of the previous PCA categories is provided in **Appendix A**.

[53] NSET Subcommittee, NSTC, EOP, *The National Nanotechnology Initiative Strategic Plan,* February 2014, http://nano.gov/sites/default/files/pub_resource/2014_nni_strategic_plan.pdf.

Total funding for the NNI Signature Initiatives in FY2014 was $298.1 million, up $18.2 million (6.5%) from FY2013. The President requested $291.3 million for FY2015.

The following paragraphs provide a brief description of each NSI, as articulated by the NSET Subcommittee, and current and requested funding levels:[54]

**Nanotechnology for Solar Energy Collection and Conversion.** The Nanotechnology for Solar Energy Collection and Conversion NSI is focused on understanding of energy conversion and storage phenomena at the nanoscale, improving nanoscale characterization of electronic properties relevant to solar energy, and utilization of the unique physical phenomena that occur on the nanoscale to help overcome current performance barriers and substantially improve the collection and conversion of solar energy. This NSI has three thrust areas: (1) improving photovoltaic solar electricity generation; (2) improving solar thermal energy generation and conversion; and (3) improving solar-to-fuel conversions. Funding in FY2014 was $67.4 million, down $6.2 million (8.4%) from FY2013. The President requested $69.2 million for FY2015.

**Sustainable Nanomanufacturing.** The Sustainable Nanomanufacturing NSI is focused on establishing manufacturing technologies for economical and sustainable integration of nanoscale building blocks into complex, large-scale systems by supporting product, tool, and process design informed by and adhering to the overall constraints of safety, sustainability, and scalability. This NSI specifically focuses at this time on high-performance structural carbon-based nanomaterials, optical metamaterials, and cellulosic nanomaterials. The nanomanufacturing NSI has two thrust areas: (1) design of scalable and sustainable nanomaterials, components, devices, and processes; and (2) nanomanufacturing measurement technologies. Funding in FY2014 was $38.4 million, up $3.7 million (10.7%) from FY2013. The President requested $36.2 million for FY2015.

**Nanoelectronics for 2020 and Beyond.** The Nanoelectronics for 2020 and Beyond NSI is focused on discovery and use of novel nanoscale fabrication processes and innovative concepts to produce revolutionary materials, devices, systems, and architectures to advance the field of nanoelectronics. The nanoelectronics NSI has five thrust areas: (1) exploring new or alternative "state variables" for computing; (2) merging nanophotonics with nanoelectronics; (3) exploring carbon-based nanoelectronics; (4) exploiting nanoscale processes and phenomena for quantum information science; and (5) expanding the national nanoelectronics research and manufacturing infrastructure network. Funding in FY2014 was $76.7 million, down $10.6 million (12.1%) from FY2013. The President requested $71.5 million for FY2015.

**Nanotechnology Knowledge Infrastructure.** The Nanotechnology Knowledge Infrastructure NSI has four thrust areas that focus efforts on cooperative interdependent development of (1) a diverse collaborative community; (2) an agile modeling network coupling experimental basic research, modeling, and applications development; (3) a sustainable cyber-toolbox for nanomaterials design; and (4) a robust digital nanotechnology data and information infrastructure. Funding in FY2014 was $32.1 million, up $24.6 million (328.0%) from FY2013. The President requested $26.2 million for FY2015.

[54] NSET Subcommittee, NSTC, EOP, *The National Nanotechnology Initiative Strategic Plan,* February 2014, http://nano.gov/sites/default/files/pub_resource/2014_nni_strategic_plan.pdf.

**Nanotechnology for Sensors and Sensors for Nanotechnology.** The Nanotechnology for Sensors and Sensors for Nanotechnology NSI has two thrust areas: (1) to develop and promote adoption of new technologies that employ nanoscale materials and features to overcome technical barriers associated with conventional sensors; and (2) to develop methods and devices to detect and identify engineered nanomaterials (ENMs) across their life cycles in order to assess their potential impact on human health and the environment. Funding in FY2014 was $83.5 million, up $6.7 million (8.7%) from FY2013. The President requested $88.2 million for FY2015.

### *Foundational Research*

The Foundational Research PCA includes:

- discovery and development of fundamental knowledge pertaining to new phenomena in the physical, biological, and engineering sciences that occur at the nanoscale;
- elucidation of scientific and engineering principles related to nanoscale structures, processes, and mechanisms;
- research aimed at discovery and synthesis of novel nanoscale and nanostructured materials and at a comprehensive understanding of the properties of nanomaterials ranging across length scales, and including interface interactions; and
- research directed at identifying and quantifying the broad implications of nanotechnology for society, including social, economic, ethical, and legal implications.[55]

Funding for the Foundational Research PCA in FY2014 was $539.8 million, down $41.5 million (7.1%) from FY2013. The President requested $530.4 million for FY2015.

### *Nanotechnology-Enabled Applications, Devices, and Systems*

The Nanotechnology-Enabled Applications, Devices, and Systems PCA includes: R&D that applies the principles of nanoscale science and engineering to create novel devices and systems, or to improve existing ones, and the incorporation of nanoscale or nanostructured materials and the processes required to achieve improved performance or new functionality, including metrology, scale up, manufacturing technology, and nanoscale reference materials and standards. To meet this definition, the enabling science and technology must be at the nanoscale, but the applications, systems, and devices themselves are not restricted to that size.[56]

[55] NSET Subcommittee, NSTC, EOP, *The National Nanotechnology Initiative Strategic Plan,* February 2014, http://nano.gov/sites/default/files/pub_resource/2014_nni_strategic_plan.pdf.

[56] NSET Subcommittee, NSTC, EOP, *The National Nanotechnology Initiative Strategic Plan,* February 2014, http://nano.gov/sites/default/files/pub_resource/2014_nni_strategic_plan.pdf.

Funding for the Nanotechnology-Enabled Applications, Devices, and Systems PCA in FY2014 was $363.2 million, up $1.8 million (0.5%) from FY2013. The President requested $363.0 million for FY2015.

### *Research Infrastructure and Instrumentation*

The Research Infrastructure and Instrumentation PCA includes the establishment and operation of user facilities and networks, acquisition of major instrumentation, workforce development, and other activities that develop, support, or enhance the nation's physical or human infrastructure for nanoscale science, engineering, and technology. This PCA includes R&D pertaining to the tools needed to advance nanotechnology research and commercialization, including next generation instrumentation for characterization, measurement, synthesis, and design of materials, structures, devices, and systems. While student support to perform research is captured in other categories, dedicated educational and workforce efforts ranging from curriculum development to advanced training are included in this PCA as resources supporting the human infrastructure of the NNI.[57]

Funding for the Research Infrastructure and Instrumentation PCA in FY2014 was $223.2 million, up $10.7 million (5.0%) from FY2013. The President requested $239.8 million for FY2015.

### *Environment, Health, and Safety*

The Environment, Health, and Safety PCA includes R&D primarily directed at understanding the environmental, health, and safety impacts of nanotechnology development and corresponding risk assessment, risk management, and methods for risk mitigation.[58]

Funding for the Environment, Health, and Safety PCA in FY2014 was $113.3 million, down $1.8 million (1.6%) from FY2013. The President requested $112.4 million for FY2015.

**Table 2. Funding by Program Component Area, FY2013-FY2015 Request**

(in millions of current dollars)

| PCA | FY2013 Actual | FY2014 Estimated | FY2015 Request |
|---|---|---|---|
| Nanotechnology Signature Initiatives | $ 279.9 | $ 298.1 | $ 291.3 |
| *Nanotechnology for Solar Energy Collection and Conversion* | *73.6* | *67.4* | *69.2* |
| *Sustainable Nanomanufacturing* | *34.7* | *38.4* | *36.2* |
| *Nanoelectronics for 2020 and Beyond* | *87.3* | *76.7* | *71.5* |
| *Nanotechnology Knowledge Infrastructure* | *7.5* | *32.1* | *26.2* |
| *Nanotechnology for Sensors and Sensors for Nanotechnology* | *76.8* | *83.5* | *88.2* |

[57] NSET Subcommittee, NSTC, EOP, *The National Nanotechnology Initiative Strategic Plan,* February 2014, http://nano.gov/sites/default/files/pub_resource/2014_nni_strategic_plan.pdf.

[58] NSET Subcommittee, NSTC, EOP, *The National Nanotechnology Initiative Strategic Plan,* February 2014, http://nano.gov/sites/default/files/pub_resource/2014_nni_strategic_plan.pdf.

| PCA | FY2013 Actual | FY2014 Estimated | FY2015 Request |
|---|---|---|---|
| Foundational Research | 581.3 | 539.8 | 530.4 |
| Nanotechnology-enabled Applications, Devices, and Systems | 361.4 | 363.2 | 363.0 |
| Research Infrastructure and Instrumentation | 212.5 | 223.2 | 239.8 |
| Environment, Health, and Safety | 115.1 | 113.3 | 112.4 |
| **Total** | **$ 1,550.2** | **$ 1,537.5** | **$1,536.9** |

**Source:** NSET Subcommittee, NSTC, EOP, *The National Nanotechnology Initiative: Supplement to the President's FY2015 Budget*, March 2014, http://nano.gov/sites/default/files/pub_resource/nni_fy15_budget_supplement.pdf.

**Notes:** Totals may differ from the sum of the components due to rounding.

## Table 3. NNI Funding, by Program Component Area, FY2006-FY2012

(in millions of current dollars, except for final column)

| PCA | FY2006 Actual | FY2007 Actual | FY2008 Actual | FY2009 Actual | ARRA (P.L. 111-5) | FY2010 Actual | FY2011 Actual | FY2012 Actual |
|---|---|---|---|---|---|---|---|---|
| Fundamental Phenomena and Processes | 455.9 | 480.6 | 478.5 | 479.2 | 130.6 | 490.5 | 567.9 | 518.8 |
| Nanomaterials | 265.1 | 258.3 | 285.1 | 331.9 | 178.3 | 358.9 | 348.2 | 358.5 |
| Nanoscale Devices and Systems | 319.6 | 344.7 | 372.7 | 435.2 | 68.0 | 542.1 | 454.7 | 457.9 |
| Instrumentation Research, Metrology, and Standards | 51.0 | 52.5 | 69.0 | 90.8 | 12.4 | 89.4 | 73.2 | 58.3 |
| Nanomanufacturing | 33.8 | 48.1 | 47.1 | 75.6 | 28.5 | 84.8 | 92.0 | 114.9 |
| Major Research Facilities and Instrumentation Acquisition | 152.4 | 152.4 | 196.4 | 177.6 | 72.5 | 190.2 | 185.8 | 197.1 |
| Societal Dimensions | 73.5 | | | | | | | |
| - Environment, Health, and Safety | | 48.3 | 67.9 | 74.5 | 12.0 | 90.2 | 88.0 | 109.9 |
| - Education & Societal Dimensions | | 39.2 | 37.7 | 36.8 | 9.0 | 66.9 | 37.5 | 41.9 |
| **TOTAL[a]** | **1,351.2** | **1,424.1** | **1,554.4** | **1,701.5** | **511.3** | **1,912.8** | **1,847.3** | **1857.3** |

**Sources:** NSET Subcommittee, NSTC, EOP, *The National Nanotechnology Initiative: Research and Development Leading to a Revolution in Technology and Industry, Supplement to the President's FY2008 Budget*, July 2007. NSET Subcommittee, NSTC, EOP, *National Nanotechnology Initiative: FY2009 Budget & Highlights*, February 2008. NSET Subcommittee, NSTC, EOP, *The National Nanotechnology Initiative: Research and Development Leading to a Revolution in Technology and Industry, Supplement to the President's FY2010 Budget*, May 2009. NSET Subcommittee, NSTC, EOP, *The National Nanotechnology Initiative: Research and Development Leading to a Revolution in Technology and Industry, Supplement to the President's FY2011 Budget*, The White House, February 2010. NSET Subcommittee, NSTC, EOP, *The National Nanotechnology Initiative: Research and Development Leading to a Revolution in Technology and Industry, Supplement to the President's FY2012 Budget*, February 2011. NSET Subcommittee, NSTC, EOP, *The National Nanotechnology Initiative: Research and Development Leading to a Revolution in Technology and Industry, Supplement to the President's FY2013 Budget*, February 2012. NSET Subcommittee, NSTC, EOP, *The National Nanotechnology Initiative: Research and Development Leading to a Revolution in Technology and Industry, Supplement to the President's FY2014 Budget*, May 2013.

**Notes:** n/a = not available

a. Totals may differ from the sum of the components due to rounding.

## Centers, Networks, and User Facilities

A key facet of the National Nanotechnology Initiative has been the development of an extensive infrastructure of interdisciplinary research and education centers, networks, and user facilities. The centers and user facilities are located at universities and federal laboratories across the country. Centers and networks provide opportunities and support for multidisciplinary research among investigators from a variety of disciplines and research sectors, including academia, industry, and government laboratories. Such multidisciplinary research not only can lead to advances in knowledge, but also may foster relationships that further the development of basic research results into devices and other applications.

Many agencies support such centers. Among them:

- The NSF has established a variety of university-based centers supporting nanotechnology research, including Nanoscale Science and Engineering Centers (NSECs), Engineering Research Centers (ERCs), Nanosystems Engineering Research Centers (NERCs), Science and Technology Centers, Materials Research Science and Engineering Centers (MRSECs), Nanoscale Science and Engineering Networks (NSENs), and Centers for Chemical Innovation (CCIs).
- The NIH has established more than 25 centers, including five university-based Nanomedicine Development Centers; a Nanotechnology Characterization Laboratory, established by the National Cancer Institute (NCI), in partnership with NIST and the Food and Drug Administration; nine university-based Centers of Cancer Nanotechnology Excellence, established under the NCI's Alliance for Nanotechnology in Cancer initiative; four university-based centers, established by the National Heart, Lung, and Blood Institute under its Program of Excellence in Nanotechnology; and six university-based NCI Cancer Nanotechnology Training Centers. In addition, NSF and the Environmental Protection Agency have established two university-based Centers for Environmental Implications of Nanotechnology (CEIN).
- The DOD supports three university-based nanotechnology research centers, as well as the Institute for Nanoscience at the Naval Research Laboratory.
- The DOE has established five Nanoscale Science Research Centers (NSRCs). The NSRC user facilities are co-located with DOE national labs.
- NIST has established a Center for Nanoscale Science and Technology (CNST).
- NIOSH has established a Nanotechnology Research Center to conduct research into the application of nanoparticles and nanomaterials in occupational safety and health and the implications of nanoparticles and nanomaterials for work-related injury and illness.
- The USDA Forest Service has established Cellulose Nanomaterial Pilot Facilities, including the Process Development Center/University of Maine School of Forest Resources and the Advance Structures and Composites Center and the Forest Products Laboratory.

Some centers are designated as user facilities and are available to researchers not located at the center. User facilities are designed to allow outside researchers to take advantage of facilities,

equipment, tools, and expertise. These shared resources provide researchers the opportunity to conduct research, characterize materials, and test products using equipment and facilities that their individual companies, universities, or organizations could not afford to acquire, support, or maintain. Conditions for user access vary by facility and agency. In general, users are not charged for pre-competitive, non-proprietary work leading to publication, and are charged on a cost-recovery basis for proprietary work. In some cases, the user facilities are located at federal government laboratories (e.g., the Department of Energy's NSRCs, and the NIST CNST); other user facilities are located at universities and supported with federal funds (e.g., NSF's university-based centers in the National Nanotechnology Infrastructure Network (NNIN)).

As mentioned earlier, the 21st Century Nanotechnology R&D Act of 2003 directed the establishment of two centers, the American Nanotechnology Preparedness Center and the Center for Nanomaterials Manufacturing. According to the NSET Subcommittee, the requirement to establish the American Nanotechnology Preparedness Center was met by NSF's establishment of the Network for Nanotechnology in Society, comprised of centers at the University of California, Santa Barbara (with the participation of Harvard University and the University of South Carolina) and the University of Arizona.[59] These centers were funded under NSF's Nanoscale Science and Engineering Center (NSEC) program and did not include participation by any other NSET Subcommittee agency.[60] The NSET Subcommittee states that the requirement for establishing the Center for Nanomaterials Manufacturing was met by NSF's establishment of a National Nanomanufacturing Network (NNN) comprised of four NSECs. The Center for Integrated Hierarchical Manufacturing at the University of Massachusetts Amherst is the main node of the NNN.[61] The NNN NSECs were established by NSF in collaboration with DOD and NIST, but exclusively with NSF funds.[62]

# NNI Assessments by PCAST, NRC: Selected Issues, Findings, and Recommendations

The 21st Century Nanotechnology R&D Act of 2003 (P.L. 108-153) requires periodic external reviews of the National Nanotechnology Program (NNP) by the National Research Council (NRC) of the National Academy of Sciences (NAS),[63] and by the National Nanotechnology Advisory Panel (NNAP), directing the President to "establish or designate a National Nanotechnology Advisory Panel." Both President Obama[64] and President Bush[65] issued executive orders designating the President's Council of Advisors on Science and Technology to serve as the NNAP. References to PCAST in this section refer to the council operating in its capacity as the NNAP.

[59] Private telephone communication between CRS and NSTC staff, January 31, 2008.

[60] Private email communication between CRS and NSF staff, January 31, 2008.

[61] Private telephone communication between CRS and NSTC staff, January 31, 2008.

[62] Private email communication between CRS and NSF staff, January 31, 2008.

[63] The NAS and NRC are part of the National Academies which also includes the National Academy of Engineering and the Institute of Medicine.

[64] Executive Order 13539.

[65] Executive Order 13349.

Under the act, the NNAP is to report to the President and Congress on its assessments of the NNP at least once every two years on a variety of factors, including trends and developments in nanotechnology science and engineering; progress made in implementing the NNP; the need to revise the program; the balance among the program components, including funding levels for the program component areas; whether the program component areas, priorities, and technical goals developed by the NSTC are helping to maintain U.S. leadership in nanotechnology; the management, coordination, implementation, and activities of the program; and whether societal, ethical, legal, environmental, and workforce concerns are adequately being addressed.

In addition, the act directs the NNCO to enter into an arrangement with NRC to conduct a triennial review of the program. Each review is to include an evaluation of the technical accomplishments of the program, including the following:

- a review of whether the program has achieved the goals under the metrics established by the NSTC;
- a review of the program's management and coordination across agencies and disciplines;
- a review of the funding levels at each agency for the program's activities and the ability of each agency to achieve the program's stated goals with that funding;
- an evaluation of the program's success in transferring technology to the private sector;
- an evaluation of whether the program has been successful in fostering interdisciplinary research and development;
- an evaluation of the extent to which the program has adequately considered ethical, legal, environmental, and other appropriate societal concerns;
- recommendations for new or revised program goals;
- recommendations for new research areas, partnerships, coordination and management mechanisms, or programs to be established to achieve the program's stated goals;
- recommendations on policy, program, and budget changes with respect to nanotechnology research and development activities; recommendations for improved metrics to evaluate the success of the program in accomplishing its stated goals;
- a review of the performance of the NNCO and its efforts to promote access to and early application of the technologies, innovations, and expertise derived from program activities to agency missions and systems across the federal government and to U.S. industry;
- an analysis of the relative position of the United States compared to other nations with respect to nanotechnology R&D, including the identification of any critical research areas where the United States should be the world leader to best achieve the goals of the program; and
- an analysis of the current impact of nanotechnology on the U.S. economy and recommendations for increasing its future impact.

The PCAST has produced five assessments of the NNI and the NRC has produced two. The assessment reports are:

- *The National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the National Nanotechnology Advisory Panel*, NNAP/PCAST, May 2005 (hereinafter referred to as "*First Assessment*").
- *A Matter of Size: Triennial Review of the National Nanotechnology Initiative*, NAS/NRC, 2006.
- *The National Nanotechnology Initiative: Second Assessment and Recommendations of the National Nanotechnology Advisory Panel*, NNAP/PCAST, April 2008 (hereinafter referred to as "*Second Assessment*").
- *Report to the President and Congress on the Third Assessment of the National Nanotechnology Initiative*, NNAP/PCAST, March 2010, (hereinafter referred to as "*Third Assessment*").
- *Report to the President and Congress on the Fourth Assessment of the National Nanotechnology Initiative*, NNAP/PCAST, April 2012 (hereinafter referred to as "*Fourth Assessment*").
- *Triennial Review of the National Nanotechnology Initiative*, NRC, 2013.
- *Report to the President and Congress on the Fifth Assessment of the National Nanotechnology Initiative*, NNAP/PCAST, October 2014 (hereinafter referred to as "*Fifth Assessment*").

Highlights of recommendations included in the *Fifth Assessment* are provided below, followed by selected findings and recommendations of each of the assessments grouped by broad issue area.

## Selected Recommendations from PCAST's *Fifth Assessment*

In its *Fifth Assessment,* PCAST asserts that nanotechnology and the NNI are at a "critical transition point." Technologically, PCAST states, there will be an "evolution from nanoscale components to interdisciplinary nano-systems," a change in the complexity and potential of nanotechnology. Organizationally, PCAST states the need for the NNI to evolve from "a foundational research-based initiative to one that also provides the necessary focus to ensure rapid commercialization of nanotechnology."[66] PCAST asserts the importance of adopting an increased focus on enabling commercialization of research in the context of international competition.

Further, PCAST asserts, as its "primary conclusion," that

> the United States will only be able to claim the rewards that come from investing in nanotechnology research and sustaining an overarching Federal initiative if the Federal interagency process, the Office of Science and Technology Policy (OSTP), and the agencies themselves transition their nanotechnology programmatic efforts beyond supporting and

[66] PCAST (acting as the NNAP), Report to the President and Congress on the Fifth Assessment of the National Nanotechnology Initiative, October 2014, http://www.whitehouse.gov/sites/default/files/microsites/ostp/PCAST/pcast_fifth_nni_review_oct2014_final.pdf.

> reporting on basic and applied research and toward building program, coordination, and leadership frameworks for translating the technologies into commercial products.

PCAST identifies the "three most important recommendations" of its *Fifth Assessment* as:

1. transitioning from the NNI's current use of Nanotechnology Signature Initiatives to the concept of Grand Challenges (discussed in the box "Characteristics of Nanotechnology Signature Initiatives and Grand Challenges");
2. the establishment of a standing committee of cross-sector nanotechnology experts that advises the nanotechnology activities of the federal government, and an NSTC process that enables cross-funding of priorities to address Grand Challenges; and
3. the need for a more formal systems of metrics to assess the effectiveness of NNI research and commercialization activities.

In addition, PCAST recommended an expansion of the National Science Foundation's iCorps program to include a specific focus on entrepreneurship in the nanotechnology area; the identification of potential Institutes for Manufacturing Innovation dedicated to nanomanufacturing as part of the President's proposed National Network for Manufacturing Innovation;[67] and additional five-year support for single-investigator pursuing high-risk research in nanoscience and nanotechnology. PCAST adds that, while it encourages the NNI to provide additional focus on and resource for the commercial transition of maturing nanotechnologies, it affirms the importance of the NNI's continuing support for discovery and exploratory research.

While acknowledging that "much of the analysis and many of the recommendations are not new," PCAST asserts that implementation of its recommendations is critical to the success of the NNI, adding

> If another two years passes without these kinds of changes, we believe the value of a centrally-reported NNI will be substantially decreased. The next PCAST review will most certainly focus on the success of this implementation.[68]

[67] For information about the President's proposed National Network for Manufacturing Innovation, see CRS Report R42625, *The Obama Administration's Proposal to Establish a National Network for Manufacturing Innovation*, by John F. Sargent Jr.

[68] PCAST (acting as the NNAP), *Report to the President and Congress on the Fifth Assessment of the National Nanotechnology Initiative*, October 2014, pp. 3-4, http://www.whitehouse.gov/sites/default/files/microsites/ostp/PCAST/pcast_fifth_nni_review_oct2014_final.pdf.

### Characteristics of Nanotechnology Signature Initiatives and Grand Challenges

In its *Fifth Assessment,* PCAST recommends replacing the NNI's Nanotechnology Signature Initiatives with "Grand Challenges." This box provides information and differentiation on the characteristics associated with NSIs and Grand Challenges.

According to the NSET Subcommittee, the NNI implemented Nanotechnology Signature Initiatives "to enable the rapid advancement of science and technology in the service of national economic, security, and environmental goals by focusing resources on critical challenges and R&D gaps."[69] NSIs provide a mechanism for increased collaboration on topical areas that the NNI deems likely to benefit from close and targeted interagency interactions. NSIs employ a broad range of funding mechanism to foster innovation and accelerate nanotechnology development. The first three NSIs were initiated in 2010 and are focused on solar energy, sustainable manufacturing, and next-generation electronics. In 2012, the NNI added NSIs on informatics and sensors, bringing the total number of NSIs to five.

In its *Fifth Assessment*, PCAST defines the term "Grand Challenges" and differentiates it from a Nanotechnology Signature Initiative:

> While an NSI is shaped by the coordination of three or more Federal agencies around a topic, a Grand Challenge is a large, outward-facing effort with a specific, measurable goal. A Grand Challenge has a well-defined technical goal with a story-telling case that inspires different sectors to invest in achieving the goal. Most Grand Challenges address an issue of significant societal impact. An example is the goal of the DOE SunShot Initiative: "reduce the total costs of photovoltaic solar energy systems by about 75% so that they are cost competitive at large scale with other forms of energy without subsidies before the end of the decade." A nanotechnology Grand Challenge should be audacious but achievable and stimulate the network of activities that will drive scientific ideas to commercial nanotechnology and catalyze new discovery for technologies of the future.[70]

In addition, PCAST states that Grand Challenges: have a measurable end-point; require advances in fundamental scientific knowledge, tools, and infrastructure for successful completion; have clear milestones en route to the final goal that are both measurable and valuable in their own right; are integrating, with solutions requiring the involvement of multiple disciplines that, in many cases, do not typically interact; span from fundamental science to engineering demonstration and, upon completion, to commercialization; are too big to be undertaken by a single institution or even a few institutions.

## NNI Program Management

PCAST's *Fifth Assessment* of the NNI recommended several changes to the management of the NNI, including:

- Replacing Nanotechnology Signature Initiatives with Grand Challenges (discussed earlier);
- Establishing a mechanism for engaging research, development, and industrial stakeholders in the identification and selection of Grand Challenges;
- Using innovation prize competitions and public-private partnerships to reach critical milestones toward completion of Grand Challenges;
- Selecting leaders for each Grand Challenge and including them in NSET leadership roles;

[69] NNI website, http://www.nano.gov.

[70] PCAST (acting as the NNAP), *Report to the President and Congress on the Fifth Assessment of the National Nanotechnology Initiative*, October 2014, pp. 27-28, http://www.whitehouse.gov/sites/default/files/microsites/ostp/PCAST/pcast_fifth_nni_review_oct2014_final.pdf.

- Putting the PCAST review of the NNI on a three-year time interval concurrent with the National Research Council's review;
- Establishing a separate standing committee of cross-sector nanotechnology experts to provide guidance to the NNI (but not to function in an evaluative capacity); and
- Establishing a common set of evaluation metrics to quantify and report the impact on workforce, productivity, and scientific knowledge in nanotechnology[71]

In its 2013 *Triennial Review of the National Nanotechnology Initiative* draft, the NRC identified five crosscutting topics:

> First, it is essential to identify and support the members of the NNI nanotechnology community....
>
> Second, strengthening NNI planning, management, and coordination can be enabled by developing and implementing interagency plans for focused areas—the signature initiatives and the working groups....
>
> Third, the NNI website (www.nano.gov) needs to serve the various stakeholder groups—including researchers, small and large businesses, educators and students, and the mass media—better....
>
> Fourth, the NSET Subcommittee, NNI agencies, and the NNCO need to take advantage of advances in technology and methods for data collection and social-network analysis to develop and test specific metrics for assessing progress toward NNI goals and informing program management....
>
> Fifth, the NNI would benefit from identifying, sharing, and implementing best practices, such as those described in this report, especially [those] related to technology transfer and commercialization.[72]

In support of these themes, the NRC made a number of recommendations related to program management (as well as recommendations to address other issues; these are presented later in this section). Among the NRC recommendations:

- The NSET Subcommittee should regularly assess working groups, re-defining or eliminating ones that are no longer useful and forming new working groups as needed. The NRC recommended the NSET Subcommittee consider establishing working groups on facility oversight and coordination and on education and workforce development.
- Each NSET Subcommittee working group should address specific goals, develop annual plans for outputs and shorter-term outcomes, and highlight ties to the NNI signature initiatives.

[71] PCAST (acting as the NNAP), *Report to the President and Congress on the Fifth Assessment of the National Nanotechnology Initiative*, October 2014, pp. 6-7, http://www.whitehouse.gov/sites/default/files/microsites/ostp/PCAST/pcast_fifth_nni_review_oct2014_final.pdf.

[72] NRC, *Triennial Review of the National Nanotechnology Initiative*, draft, 2013, pp. 90-91.

- The NSET Subcommittee should inform and obtain input from the NSTC Committee on Technology with respect to NNI objectives and plans at least once a year.
- The NNI website should be redesigned to provide portals and guidance customized to meet the needs of a variety of NNI stakeholder communities, including companies, user facilities, users, educators, and the media.
- Each signature initiative team should develop a strategic plan that includes specific goals with quantifiable technical targets where possible, milestones, expected outputs and short-term outcomes, and that identifies the roles and responsibilities of agencies, the NSET Subcommittee, and the NNCO.
- The NSET Subcommittee should incentivize groups in nanotechnology-enabled industries to participate in developing technical roadmaps and in partnering to address long-term research needs through agency efforts such as the NIST Advanced Manufacturing Technology Consortium program (AmTech).[73]

In its 2013 draft report, the NRC (like PCAST in its *Third Assessment*, see below) also expressed concerns about the adequacy of authority of NSET Subcommittee representatives within their agencies and their ability to influence budget decision making. The NRC does acknowledge that "there may be a tradeoff between authority in the agencies and the ability to devote time and effort to the many NNI coordinating activities."[74]

In its *Fourth Assessment*, PCAST lauded the NNI's "significant progress" in addressing several issues identified in the *Third Assessment*, but expressed concern about the lack of progress in others, notably "significant and persistent hurdles to an optimal structure and management of the initiative." In particular, PCAST noted that despite the publication in 2011 of the National Nanotechnology Initiative Strategic Plan,[75]

> individual agency contributions lack the cohesion of an overarching framework, and there is no clear connection between the goals and objectives of the NNI strategic plan with those of individual agencies.[76]

While recognizing that some agencies do not have dedicated nanotechnology programs, but rather decentralized nanotechnology activities across multiple organizational units, PCAST recommended the development of implementation plans by each agency—in consultation with external stakeholders—that discuss the alignment of agency activities with the objectives of the NNI strategic plan.

PCAST renewed its recommendations that each NSET Subcommittee agency have senior representatives with decision-making authority participate in coordination activities of the NNI, and that the NSET Subcommittee dedicate 0.3% of NNI funding to the NNCO to ensure appropriate staffing and budget levels to effectively develop, monitor, and assess NNI programs.

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[73] NRC, *Triennial Review of the National Nanotechnology Initiative*, draft, 2013, pp. 1-9.

[74] NRC, *Triennial Review of the National Nanotechnology Initiative*, draft, 2013, p. 6.

[75] NSTC Subcommittee, NSTC, EOP, *National Nanotechnology Initiative Strategic Plan*, February 2011, http://nano.gov/sites/default/files/pub_resource/2011_strategic_plan.pdf.

[76] PCAST, EOP, *Fourth Assessment*, April 2012.

In 2011, NNCO funding was $2.9 million; if funding had been set at 0.3%, the NNCO would have received $5.5 million in FY2011.[77]

To expand and strengthen the role of the NNCO in the NNI, PCAST also recommended appointing the NNCO director as a co-chair of the NSET Subcommittee and allowing non-federal experts to serve as NNCO director.[78]

PCAST further recommended creating a standing PCAST Nanotechnology Steering Committee of experts from industry, academia, and civil society to provide more frequent and in-depth guidance.[79] This recommendation raises the question of whether the role envisioned for the NNAP, as authorized by the 21st Century Nanotechnology Research and Development Act, is appropriately being served by PCAST or whether it might be better served by the establishment of a separate, dedicated entity. In its first assessment of the NNI, the NRC recommended that

> the federal government [should] establish an independent advisory panel with specific operational expertise in nanoscale science and engineering; management of research centers, facilities, and partnerships; and interdisciplinary collaboration to facilitate cutting-edge research on and effective and responsible development of nanotechnology.[80]

Coming after President Bush's designation of PCAST to serve as the legislatively mandated NNAP, this recommendation may suggest the need for a separate, NNI-only focused entity to serve as the NNAP. Critics of the use of PCAST to serve as the NNAP maintain that the scope and depth of expertise needed to provide effective guidance on the NNI requires an independent panel of people with nanotechnology-specific and interdisciplinary expertise and an undivided focus. Supporters of using PCAST for this function assert that a single advisory panel provides an integrated perspective, reduces unnecessary cost and management burdens, and allows for expertise to be added to the panel or accessed through non-member technical advisory groups.

In its *Third Assessment*, PCAST praised the NNI for having "distinguished itself during its first decade as a successful cooperative venture," and further described the initiative as well-organized and well-managed.[81] Nevertheless, in both its *Third Assessment* and *Fourth Assessment*, PCAST offered a number of recommendations for improving NNI program management. In its *Third Assessment*, PCAST stated that "the NNCO should broaden its impact and efficacy and improve its ability to coordinate and develop NNI programs and policies." In this regard, PCAST recommended that OSTP undertake the following actions:

- Require each agency in the NNI to have senior representatives with decision-making authority participate in coordination activities of the NNI.
- Strengthen the NNCO to enhance its ability to act as the coordinating entity for the NNI.

[77] Ibid.

[78] Ibid

[79] Ibid.

[80] NRC, *A Matter of Size: Triennial Review of the National Nanotechnology Initiative*, 2006.

[81] PCAST, EOP, *Third Assessment,* March 12, 2010.

- Dedicate 0.3% of NNI funding to the NNCO to ensure the appropriate staffing and budget to effectively develop, monitor and assess NNI programs.[82]

In its 2013 budget supplement, the NSET Subcommittee characterized these program management recommendations as actions "unlikely or not needed." With respect to requiring the participation of senior agency representatives with decision-making authority, the NSET Subcommittee replied that member agencies make their own decisions with regard to representation. The NSET Subcommittee also responded to PCAST's recommendation that the NNCO's coordination function be strengthened and better funded. First, the NSET Subcommittee reasserted that it is the NSET Subcommittee, not the NNCO, that serves as the coordinating entity for the NNI, and that the NNCO serves to provide administrative support to the NSET Subcommittee. Second, the NSET Subcommittee stated that it did not support providing the NNCO a fixed percentage of the overall NNI investment, explaining that NNCO activities are based on programmatic needs as proposed each year by the NNCO and vetted by the NSET Subcommittee's Budget Steering Group.

## Funding

A key question for federal policy makers is how much funding should be provided for nanotechnology R&D, and how this funding should be allocated among program component areas and cross-cutting activities. While NNI funding grew from $464 million in FY2001 to a peak of $1.913 billion in FY2010, regular appropriations for the NNI subsequently fell to an estimated $1.857 billion in FY2012. The President has requested $1.702 billion for FY2014.

In its 2013 draft report, the NRC noted that, given the constrained federal budget environment, agencies will need to set priorities for R&D investments and expand coordination of nanotechnology efforts.[83]

In its *Third Assessment*, PCAST recommended that the federal government increase funding for the NNI to ensure that the United States retains its

> leadership role in the development and commercialization of nanotechnology in the face of mounting competition from countries that have responded to the example set by the NNI.[84]

PCAST cautioned that in undertaking these new investments the NNI should maintain or expand the level of funding devoted to basic nanotechnology research.

Similarly, in its first assessment of the NNI, the NRC recommended

> the federal government [should] sustain investments in a manner that balances the pursuit of shorter-term goals with support for longer-term R&D and that ensures a robust supporting infrastructure, broadly defined. Supporting long-term research effectively will require

[82] Ibid. Two other PCAST program management recommendations related to metrics and appointment of individuals to the NNCO to lead interagency EHS and standards development efforts are discussed elsewhere in this section.

[83] NRC, *Triennial Review of the National Nanotechnology Initiative*, draft, 2013, p. 81.

[84] PCAST, EOP, *Report to the President and Congress on the Third Assessment of the National Nanotechnology Initiative*, March 12, 2012, http://www.whitehouse.gov/sites/default/files/microsites/ostp/pcast-nni-report.pdf.

> making new funds available that do not come at the expense of much-needed ongoing investment in U.S. physical sciences and engineering research.[85]

## U.S. Technological and Industrial Leadership

Given the economic, societal, and national security potential of nanotechnology, Congress maintains ongoing interest in the competitive position of the United States in this emerging field. In its 2013 draft report, the NRC noted that Battelle/*R&D Magazine*'s 2012 Global R&D Funding Forecast[86] predicted the United States' share of total R&D[87] would decrease from 32.8% in 2010 to 31.1% in 2012, while the share funded by the nations of Asia is expected to grow from 34.3% to 36.7%, potentially posing long-term challenges to U.S. competitiveness. Nevertheless, the NRC notes that R&D spending is only one factor among many (such as tax, regulatory, health care, energy, and education policies; subsidy programs; currency valuation; science-based industrial parks; and worker training) that can affect national competitiveness. The NRC recommended that the NSET Subcommittee periodically review the status of the competitive environment for nanotechnology-enabled industry in the United States relative to that of other nations.[88]

In its *Fifth Assessment,* PCAST recognized the global competition for nanotechnology talent and recommended that NNI agencies support single investigators engaged in creative, high-risk research, and to fund at least five new National Security Science and Engineering Faculty Fellowship-style grants in nanoscience and nanotechnology annually. PCAST also offered strong support for nanoscale research centers and infrastructure networks—particularly the Next Generation National Nanotechnology Infrastructure Network—for training transdisciplinary scientists and engineers.

In its *Fourth Assessment,* PCAST asserted that the NNI "remains a successful cooperative venture" that has had a "catalytic and substantial impact" on the growth of the U.S. nanotechnology industry, and concluded that

> the United States is today, by a wide range of measures, the global leader in this exciting and economically promising field of research and technological development.[89]

PCAST attributed the U.S. leadership position in nanotechnology, in large part, to the NNI.

The assertion of U.S. leadership in nanotechnology echoes PCAST's findings in its *Third Assessment*. That assessment, however, noted that U.S. leadership was threatened by several aggressive competitors:

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[85] NRC, *A Matter of Size: Triennial Review of the National Nanotechnology Initiative*, 2006, http://books.nap.edu/catalog.php?record_id=11752.

[86] Battelle and *R&D Magazine*, "2012 Global R&D Funding Forecast," December 2011, http://battelle.org/docs/default-document-library/2012_global_forecast.pdf?sfvrsn=2, accessed 11/15/2012.

[87] Total R&D includes nanotechnology and all other fields.

[88] NRC, *Triennial Review of the National Nanotechnology Initiative*, draft, 2013, p. 81.

[89] PCAST, EOP, *Report to the President and Congress on the Fourth Assessment of the National Nanotechnology Initiative*, April 2012, http://www.whitehouse.gov/sites/default/files/microsites/ostp/PCAST_2012_Nanotechnology_FINAL.pdf.

> The United States is clearly the world's leader in nanotechnology R&D and commercialization based on research funding, total number of papers in the most significant scientific publications, patents filed and granted, private sector funding for new and existing companies developing nanotechnologies, and sales of nanotechnology-based products. However, foreign competitors, particularly China, South Korea, Germany, and Japan, are making gains on many of these same metrics. China in particular has significantly increased its share of nanotechnology research publications and patents and now supports nanotechnology as a larger fraction of its total scientific research compared to the United States.... Though still the leader in nanotechnology R&D and commercialization, the United States is losing ground to foreign competitors, particularly China, South Korea, Germany, and Japan, on a number of key metrics of research output and commercial activity.[90]

PCAST's *Fourth Assessment* noted that "in addition to China, South Korea, and other early movers, the Russian Nanotech Corporation (RUSNANO) is now also rising as a major player, second only to the United States in its nanotechnology R&D spending."[91] PCAST cited data from Lux Research indicating that RUSNANO had increased its funding by nearly 40% to $1.05 billion, and planned to increase funding to nearly $1.5 billion by 2015.

PCAST's assessment of the U.S. leadership position was founded not on sales, growth, or market share of commercial products—common measures of global competitiveness for established products—but rather on metrics that may serve as early indicators of potential innovation, such as the U.S. share of scientific publications and patents. The use of such metrics may not be universally accepted as predictive of leadership position. Technological leadership—or even leadership in innovation—does not ensure that the economic benefits from such leadership will accrue to the United States. For example, companies may choose to manufacture products or conduct other value-added activities outside the United States. If the assessment of national competitiveness were to be expanded to include value-added activities and jobs generated or retained within the United States, then different metrics for assessing global leadership might be needed.

## Technology Commercialization

Technology commercialization involves the movement of scientific and technological insights into products and services. It is the process by which knowledge created by investments in R&D is translated into economic benefits (e.g., strengthening existing firms and establishing new ones, creating jobs, producing new products, reducing the cost of existing products and improving their performance, delivering returns to investors) and societal benefits (e.g., offering new and improved sources of renewable energy, reducing pollution and remediating environmental damage, improving human heath).

PCAST's *Fifth Assessment* of the NNI recommended several changes to improve the commercialization of nanotechnology. PCAST recommended that the NSET Subcommittee should work with federal agencies to define potential Manufacturing Innovation Institutes dedicated to nanomanufacturing as part of the President's proposed National Network for Manufacturing Innovation. PCAST also recommended expansion of the NSF iCorps program—focused on providing hands-on business knowledge to scientists and engineers on bringing

[90] PCAST, EOP, *Third Assessment,* March 12, 2010.

[91] PCAST, EOP, *Fourth Assessment,* April 2012.

technology products to market—to assist researchers engaged in nanoscience and nanotechnology research. Additionally, PCAST called for the NNCO and the Department of Commerce to establish an annual nano-focused economic development forum for academic researchers, the venture capitalists, and industry representatives to facilitate the development of business partnerships.

In its 2013 draft report, the NRC credits the NNI agencies and the NNCO for having taken steps to boost technology transfer of NNI research results, including making technology transfer a primary goal; reporting on progress in the annual budget supplement, including the amount of Small Business Innovation Research (SBIR) program and Small Business Technology Transfer (STTR) program funds going to nanotechnology research; providing access to information about the NNI and user facilities through the NNI website; and conducting workshops on regional, state, and local programs related to nanotechnology.

The NRC noted that there are a variety of cooperative research models with unique characteristics that the NNI might draw upon to facilitate technology commercialization. In this regard, the NRC recommended that the NNI agencies identify and share best practices in intellectual property management.[92]

In its *Fourth Assessment*, PCAST continued its *Third Assessment* emphasis on improving commercialization efforts, and lauded the NNI's response to commercialization-related recommendations the council made in its previous assessment, specifically:

- development of an NNCO Industry and State Liaison position and expanded efforts by the NNCO in supporting nanotechnology commercialization;
- the NILI working group's development of an agenda focused on job creation and state outreach, as well as mechanisms to incorporate industrial input in NNI planning;
- DOE programs that include industrial partners to overcome technological barriers to nanotechnology commercialization;
- NIST's plans to start the Advanced Manufacturing Technology Consortia program in FY2013 to speed development and commercialization of new products and services, including nanotechnology; and
- NIH's creation of the National Center for Advancing Translational Sciences to accelerate translation of promising technologies and clinical studies to applications and practice.[93]

Nevertheless, the PCAST co-chairs also noted in their transmittal letter to President Obama that additional work in a number of areas was still required to facilitate technology commercialization and U.S. leadership in nanotechnology:

> ... additional efforts are needed in four areas: strategic planning, program management, metrics for assessing impact, and increasing support for research on environmental, health, and safety issues associated with nanotechnology. Continued lack of attention to these

[92] NRC, *Triennial Review of the National Nanotechnology Initiative*, draft, 2013, p. 84.

[93] PCAST, EOP, *Fourth Assessment,* April 2012.

> concerns will make it harder for the U.S. to maintain its leadership role in the commercialization of nanotechnology.[94]

Previously, in its *Third Assessment*, PCAST recommended that, to maintain the U.S. leadership position in nanotechnology,

> the NNI increase its emphasis on nanomanufacturing and commercial deployment of nanotechnology-enabled products, and that the agencies within the NNI must interact and cooperate more with one another to ease the translation of scientific discovery into commercial activity.[95]

In this regard, PCAST made a number of recommendations. Among them:

- double federal funding for nanomanufacturing over five years;
- launch at least five government-industry-university partnerships modeled after the Nanoelectronics Research Initiative;
- for each nanotechnology signature initiative, develop milestones, promote strong education components, and create public-private partnerships to leverage the outcomes;
- fund at least five NSIs over the next two to three years—including ones in priority areas such as homeland security, national defense, and human health—at annual levels of $20 million to $40 million each;
- tap the Department of Commerce and the Small Business Administration for advice on how the NNI can best ensure its programs create new jobs in the United States, including mechanisms for coordinating with state efforts; and
- clarify the development pathway and sustain investments by DOE, DOD, NIST, NIH, NCI, and FDA in focused areas to accelerate technology transfer to the marketplace.[96]

In its 2013 budget supplement, the NSET Subcommittee responded to PCAST's commercialization-focused recommendations stating that "key NNI agencies" were on track to double their nanomanufacturing investments over five years, while maintaining their investments in fundamental nanotechnology research. The five agencies identified by PCAST as targets for doubling—NSF, DOE, DOD, NIST, and NIH—funded a total of $46.8 million in nanomanufacturing R&D in FY2008; in FY2012 nanomanufacturing funding for these agencies had more than doubled to $101.5 million. Agency funding was concentrated, with NSF and DOD accounting for 86% of this total. However, President Obama has requested $89.9 million in nanomanufacturing funding for these agencies for FY2014, a reduction of $11.6 million (11.4%) from the FY2012 level.[97]

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[94] Ibid.

[95] PCAST, EOP, *Third Assessment,* March 12, 2010.

[96] Ibid.

[97] NSET Subcommittee, NSTC, EOP, *The National Nanotechnology Initiative: Supplement to the President's 2013 Budget*, February 2012.

The NSET Subcommittee also said that interagency task forces for the three initial NSIs were developing coordination plans with milestones, that there was a likelihood that two additional NSIs would be added within the next year, and that the NILI working group was working in conjunction with the NNCO's Industry and State liaison to produce a work plan that includes job creation and outreach to states and industry. With respect to clarifying the development pathway, the NSET Subcommittee asserted that it is employing well-established mechanisms, such as the SBIR and STTR programs, and that it is developing new programs to accelerate technology transfer and to clarify regulatory pathways.[98]

## Standards

Standards are likely to play a critical role in many aspects of nanotechnology R&D and commercialization, among them the development of research tools, conduct of research, reproducibility of experimental results, development and enforcement of regulations, materials characterization, nanomanufacturing, and product testing and evaluation.

In its 2013 draft report, the NRC encouraged the NNI and NNCO to continue efforts focused on facilitating the development of standards:

> Standards development is critical for commercialization, use, and sound regulation of nanotechnology. The NNCO and NIST have played leading roles in this activity. NNI agencies should continue their active participation in standards development organizations and in the development of metrology and characterization tools, standard reference materials, terminology, and nomenclature.[99]

As in earlier assessments, in its *Third Assessment*, PCAST re-asserted the importance of standards stating that "the establishment of standards is essential to growth of most new technologies, and nanotechnology is no exception."[100] Further, PCAST recommended that the NNCO serve as the coordinating agency for

> collaborating with stakeholders on enabling programs such as metrology; standards including size, shape and composition of nanomaterials, and databases of physical and chemical properties of nanomaterials; and manufacturing safety.[101]

In support of this role, PCAST also recommended that an individual be appointed to the NNCO to lead interagency coordination of standards development efforts.[102] With the departure of NNCO Director Clayton Teague who had served in this capacity, the NSET Subcommittee named Dr. Ajit Jillavenkatesa, senior standards policy advisor for the National Institute of Standards and Technology, to this role. Dr. Jillavenkatesa also co-chairs the Nanotechnology Standards Panel of the American National Standards Institute (ANSI), is active in the ANSI-accredited U.S. Technical Advisory Group to the International Organization for Standardization Technical Committee 229, and participates in the NSET Subcommittee.[103]

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[98] Ibid.

[99] NRC, *Triennial Review of the National Nanotechnology Initiative*, draft, 2013, p. 83.

[100] PCAST, EOP, *Third Assessment,* March 12, 2010.

[101] Ibid.

[102] Ibid.

[103] Email communication between CRS and OSTP, August 20, 2013.

## Economic Impact Metrics and Data Collection

PCAST's *Fifth Assessment* of the NNI recommended establishing a common set of evaluation metrics to quantify and report the impact on workforce, productivity, and scientific knowledge in nanotechnology.

Economic impact metrics and data collection were also focus areas of the NRC's 2013 draft report. The NRC recommended:

- the NNI establish a framework that links high level goals with specific actions, outputs, and outcomes, linked to performance-based data;
- the NNI collect and publish nine data sets to enable a better quantitative assessment of the NNI's success, including

  (1) NNI-funded projects;

  (2) published documents resulting from NNI activities;

  (3) frequently cited and downloaded papers and patents, invited presentations, special sessions at conferences, and media reports;

  (4) number of students supported;

  (5) user-facility and network use;

  (6) technology transfer data;

  (7) education and outreach data;

  (8) U.S.-based nanotechnology job advertisements; and

  (9) NNI-related communications about environmental, health, safety, and societal implications of nanotechnology

  The NRC cautioned, however, against the exclusive use of strictly quantitative measures for assessing NNI success, stating that "well-crafted qualitative and semi-quantitative metrics and their review, supported by rigorously documented quantitative metrics, are more likely to be useful in producing evaluations that measure success and in setting NNI goals and policy."[104]
- the NSET Subcommittee and the NNCO obtain data-mining expertise to undertake the collection and collation of essential data sets, to develop analysis tools to support the management and reporting needs of the NNCO and the agencies, and to manage the process of making the data sets publicly available; and
- agencies link NNI participants to their work products, organizations, and grants, as well as to published paper and patent databases.

[104] NRC, *Triennial Review of the National Nanotechnology Initiative*, draft, 2013, p. 45.

In its *Third Assessment,* PCAST highlighted the need for economic impact metrics and data collection, recommending the development of NNI economic impact metrics; making economic impact an explicit metric in the second decade of the NNI; and lodging responsibility with a statistical agency (such as the DOC's Bureau of Economic Analysis) to estimate job creation and the value of nanotechnology products and products incorporating nanotechnology components, rather than relying on funding agencies for such estimates.[105]

In its 2013 budget supplement, the NSET Subcommittee also responded that the NNCO had engaged in discussions with the Department of Commerce about economic metrics, provided support for a symposium on the economic value of nanotechnology, and requested the NRC identify metrics to assess the success of nanotechnology as part of the council's triennial review of the NNI.[106]

In its first assessment of the NNI, the NRC also recommended a focus on development of metrics and a greater role for the DOC in economic data collection and analysis:

> [The NRC recommends] the NSET Subcommittee carry out or commission a study on the feasibility of developing metrics to quantify the return to the U.S. economy from the federal investment in nanotechnology R&D. The study should draw on the Department of Commerce's expertise in economic analysis and its existing ability to poll U.S. industry. Among the activities for which metrics should be developed and relevant data collected are technology transfer and commercial development of nanotechnology.[107]

Few efforts have been made within the federal government to understand the economic impacts of the nation's investments in the NNI. Identification and tracking of data that could serve as an indicator of success in commercializing nanotechnology research or the effects on U.S. job creation or retention has not been formalized. To the extent that federal assessments of the economic contribution of and/or potential for nanotechnology products have occurred, they have not been performed with analytical rigor. Although the Commerce Department retains its economic analysis expertise, resident primarily in the Economics and Statistics Administration's Bureau of Economic Analysis, the department's Technology Administration, which led Commerce's NNI activities and had government-wide responsibilities for technology transfer activities, was eliminated in August 2007.[108] Prior to its elimination, the Technology Administration contracted for two studies that sought to contribute to addressing this NRC recommendation: an analysis of barriers to nanotechnology commercialization performed by the University of Illinois at Springfield, and an analysis of innovation metrics conducted by the Alliance for Science and Technology Research in America (ASTRA). These reports are publicly available at Commerce Department websites.[109]

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[105] PCAST, EOP, *Third Assessment,* March 12, 2010.

[106] NSET Subcommittee, NSTC, EOP, *The National Nanotechnology Initiative: Supplement to the President's 2013 Budget*, February 2012.

[107] NRC, *A Matter of Size: Triennial Review of the National Nanotechnology Initiative*, 2006.

[108] The Technology Administration was eliminated in the America COMPETES Act (P.L. 110-69).

[109] College of Business Management, University of Illinois at Springfield, *Barriers to Nanotechnology Commercialization*, September 2007, http://www.osec.doc.gov/Report-Barriers%20to%20Nanotechnology%20Commercialization.pdf; and ASTRA, *Innovation Vital Signs Project*, July 2007. http://www.ntis.gov/pdf/Report-InnovationVitalSigns.pdf.

## Nanotechnology Workforce Education and Training

With nanotechnology advocates promising the creation of many new jobs—some have estimated the number to be in the millions—as a result of global nanotechnology investments, some have asserted that the country must prepare students for nanotechnology research, engineering, and production jobs.[110] Assessing which industries are likely to create such jobs, which skills will be needed, and in what timeframe are key challenges. If workers with nanotechnology-specific skills are needed and no workers are available domestically (e.g., U.S. citizens, resident aliens, or those in the United States on work visas), potential employers may opt to establish or move operations outside the United States to tap workers with those skills abroad. Conversely, if students are trained for jobs that do not emerge or do not emerge in the same timeframe as students are entering the job market, this investment may be lost and human capital underutilized. In addition, potential students may be discouraged from pursuing nanotechnology-related studies in the future. Close coordination among the Departments of Commerce, Education, and Labor might help to align federal education and training efforts better with the labor market for nanotechnology workers.

In its 2013 draft report, the NRC noted the NNI's recognition of the importance of nanotechnology education and workforce training, but asserted a need for better coordination and integration among NNI agencies. To this end, the NRC recommended either re-defining the scope of the Nanotechnology Public Engagement and Communications working group to undertake this work or establishing a new NSET Subcommittee Education and Workforce Development Working Group for this purpose. Similarly, in its 2006 assessment, the NRC recommended the NSET Subcommittee "create a working group on education and the workforce that engages the Department of Education and Department of Labor as active participants."

In its *Third Assessment,* PCAST found that the United States remained unchallenged in educating nanotechnology researchers. However, PCAST noted that a large number of foreign students return to their home countries after completing their education:

> The United States still trains the majority of Ph.D. students in nanoscience and nanotechnology, and though many of these students wish to remain in the United States after completing their degree programs, the data show that over one-third of these students return to their home countries and contribute to the development of nanotechnology R&D programs throughout the world.[111]

While acknowledging that the United States may gain some benefits from training nanotechnology researchers who return to their home countries, PCAST recommended the federal government undertake efforts to retain scientific and engineering talent trained in the United States:

> by developing a program to provide U.S. Permanent Resident Cards for foreign individuals who receive an advanced degree in science or engineering at an accredited institution in the

[110] Phillip J. Bond, Under Secretary for Technology, U.S. Department of Commerce, remarks, "Nanotechnology: Economic Opportunities, Societal and Ethical Challenges," NanoCommerce 2003, December 9, 2003. http://www.technology.gov/Speeches/PJB_031209.htm, *Sizing Nanotechnology's Value Chain*, Lux Research, October 2004.

[111] PCAST, EOP, *Third Assessment,* March 12, 2010.

> United States and for whom proof of permanent employment in that scientific or engineering discipline exists.[112]

PCAST also recommended that NNI agencies continue making investments in innovative and effective education, and that the NNCO consider commissioning a comprehensive evaluation of the outcomes of the overall investment in NNI education.[113]

In its 2013 budget supplement, the NSET Subcommittee responded to PCAST's *Third Assessment* workforce education and training recommendations stating that NNI agencies were contributing to the development of nanotechnology curricula for students in grade school through postdoctoral training, and that NSF is considering supporting an external study to evaluate the NNI's investment in education. In addition, while acknowledging the need to undertake efforts to retain U.S. educated foreign scientific and engineering talent in the United States, the NSET Subcommittee stated that it did not endorse specific approaches at this time.[114]

## Environmental, Health, and Safety-Related Issues

Environmental, health, and safety issues related to nanotechnology research, development, use, and disposal (nanoEHS) continue to be a focus of NNI assessments. Some analysts have described nanotechnology as a two-edged sword. On the one hand, some are concerned, for example, that nanoscale particles may enter and accumulate in vital organs, such as the lungs and brains, potentially causing harm or death to humans and animals, and that the diffusion of nanoscale particles in the environment might harm ecosystems. On the other hand, some analysts believe that nanotechnology has the potential to deliver important EHS benefits (e.g., reducing energy consumption, pollution, and greenhouse gas emissions; remediating environmental damage; curing, managing, or preventing diseases; and offering new safety-enhancing materials that are stronger, self-repairing, and able to adapt to provide protection).

Stakeholders generally agree that concerns about potential detrimental effects of nanoscale materials and devices—both real and perceived—must be addressed to protect and improve human health, safety, and the environment; create public faith and confidence in the safety of nanotechnology products; enable accurate and efficient risk assessment, risk management, and cost-benefit trade-offs; reduce EHS and related regulatory uncertainties that may impede investment;[115] foster innovation; and ensure that society can enjoy the widespread economic and societal benefits that nanotechnology may offer.

The NSET Subcommittee has sought to address nanotechnology-related EHS concerns through a variety of approaches, including agency funding for EHS-related research, increased coordination of agency EHS-related research through the NSET Subcommittee's NEHI Working Group, and development of a government-wide research strategy.

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[112] Ibid.

[113] Ibid.

[114] NSET Subcommittee, NSTC, EOP, *The National Nanotechnology Initiative: Supplement to the President's 2013 Budget*, February 2012.

[115] For more information on regulatory issues associated with nanotechnology, see CRS Report RL34332, *Engineered Nanoscale Materials and Derivative Products: Regulatory Challenges*, by Linda-Jo Schierow.

At the request of the NNCO, the NRC conducted a review of the NSET Subcommittee's 2008 nanoEHS research strategy, *Strategy for Nanotechnology-Related Environmental, Health, and Safety Research*.[116] While the NRC found that the NSET Subcommittee's 2008 strategy "could be an effective tool for communicating the breadth of federally supported research associated with developing a more comprehensive understanding of the environmental, health, and safety implications of nanotechnology" and that it was "likely to eliminate unnecessary duplication of their research efforts," it concluded that

> [the report] does not describe a strategy for nano-risk research. It lacks input from a diverse stakeholder group, and it lacks essential elements, such as a vision and a clear set of objectives, a comprehensive assessment of the state of the science, a plan or road map that describes how research progress will be measured, and the estimated resources required to conduct such research.
>
> There remains an urgent need for the nation to build on the current research base related to the EHS implications of nanotechnology—including the federally supported research described in the 2008 NNI document—by developing a national strategic plan for nanotechnology-related environmental, health, and safety research.[117]

Among its criticisms of the 2008 strategy, the NRC asserted that:

- research needs in certain categories, notably risk management and exposure assessment, were "poorly defined" or "incomplete";
- certain research needs that did not fall directly in one of the strategy's identified categories could be overlooked;
- research needs were not presented as concrete, measurable objectives, and that the implementation plan failed "to provide any sense of how success toward specific goals will be measured or what resources might be needed to achieve them";
- the gap analysis was flawed and was neither accurate nor complete in laying a foundation for a research strategy, and that consequently it was difficult to understand the priorities of selected research needs and the logic for the priorities; and
- the federal funding specifically addressing nanotechnology-related EHS issues is far less than portrayed in the NNI document and may be inadequate.

The NRC review also called for the development of a national strategic plan, not just a federal government strategic plan. The NRC asserted that the 2008 strategy's focus on federal government agency activities failed to incorporate the role of non-governmental stakeholders with the potential for contributing research and knowledge of the EHS implications of nanotechnology.

[116] NSET Subcommittee, NSTC, EOP, *Strategy for Nanotechnology-Related Environmental, Health, and Safety Research,* February 2008.

[117] NRC, *Review of Federal Strategy for Nanotechnology-Related Environmental, Health, and Safety Research,* 2009, p. 93.

In 2011, the NSET Subcommittee published *Strategy for Nanotechnology-Related Environmental, Health, and Safety Research*,[118] which sought to address some of the shortcomings of the 2008 research strategy identified by the NRC. According to the NSET Subcommittee, the strategy was informed by data collected from "the NNI agencies responsible for overseeing the manufacture and use of engineered nanomaterials and nanotechnology-enabled products"; reviews by PCAST and the NRC; and consultation with a wide variety of stakeholders, including industry, academia, non-governmental organizations, and public health advocacy organizations.[119]

The 2011 strategy identified five core nanoEHS research needs: nanomaterial measurement infrastructure, human exposure assessment, human health, environment, and risk assessment and risk management methods. For each of the nanoEHS research needs, the NSET Subcommittee set goals, identified needed research, and analyzed ongoing research. The strategy also included a chapter on informatics and modeling for nanoEHS research.

In 2012, the NRC published, *A Research Strategy for Environmental, Health, and Safety Aspects of Engineered Nanomaterials*, in response to a request from the Environmental Protection Agency to perform an independent study to develop and monitor the implementation of an integrated research strategy to address the EHS aspects of engineered nanomaterials. In putting forward its own strategy, the NRC asserted that

> Despite increasing budgets for nanotechnology-EHS research and a growing number of publications, regulators, decision-makers, and consumers still lack the information needed to make informed public health and environmental policy and regulatory decisions.[120]

The conceptual framework put forth by the NRC included three key features:

- a value-chain and life-cycle perspective that considers potential effects originating in the production and use of nanomaterials, nanomaterial-containing products, and the wastes generated;
- a focus on determining how nanomaterial properties affect key processes that are relevant to predicting both hazard and exposure; and
- a reliance on principles that help to identify emergent, plausible, and severe risks resulting from designing and engineering materials at the nanoscale, rather than an adherence to rigid definitions of engineered nanomaterials.

PCAST has also made a number of findings and recommendations related to EHS research.

In its *Fifth Assessment,* PCAST recommended that NSET

> continue development of a multidisciplinary nanotechnology environmental, health, and safety ecosystem that promotes non-animal based (alternative) test strategies for safety assessment and multi-stakeholder participation in regulatory decisionmaking and safe

[118] NSET Subcommittee, NSTC, EOP, *Environmental, Health, and Safety Research Strategy,* October 2011.

[119] NSET Subcommittee, NSTC, EOP, *Key Concepts in the 2011National Nanotechnology Initiative Environmental, Health, and Safety Research Strategy.*

[120] NRC, *A Research Strategy for Environmental, Health, and Safety Aspects of Engineered Nanomaterials*, 2012.

> implementation to facilitate market access of nanomaterials and nanotechnology-enabled products.[121]

In its *Third Assessment,* PCAST found that

> In the absence of more detailed scientific evidence—and effective assessment and communication of the evidence that does exist—the distinction between plausible and implausible risks remains unclear. The resulting uncertainty threatens to undermine confidence and trust among investors, businesses, and consumers, and could jeopardize the success of nanotechnology. This is not a hypothetical threat. Consumer and advocacy groups already have raised concerns over the use of engineered nanomaterials in products as diverse as clothing, fuel additives, and sunscreens. Businesses have been hampered by regulatory uncertainty. A number of industries have shied away from nanotechnology for fear of consumer rejection in the face of speculative concerns.[122]

In its 2006 assessment, the NRC recommended expansion of funding for nanoEHS research. The NRC specifically noted the need for assessing the effects of engineered nanomaterials on public health and the environment and recommended the development of effective methods to estimate the exposure of humans, wildlife, and other ecological receptors to source material; assess effects on human health and ecosystems of both occupational and environmental exposure; and characterize, assess, and manage the risks associated with exposure.[123] While the NRC asserted the need for additional EHS research, it did not quantify how much more was needed.

PCAST's *Fourth Assessment* lauded the "significant progress" made by the NNI to address potential EHS risks of nanotechnology, noting the rapid growth rate for EHS-focused research funding compared to overall NNI funding; the implementation of PCAST's earlier recommendation to identify a central coordinator for EHS-research within the NNCO; and for development and release of an EHS research strategy, articulating an approach that incorporates the "evolving research needs and the strategic research plans of three relevant agencies."[124] PCAST noted that the NNI strategy aligned with the findings of the 2012 NRC report, *A Research Strategy for Environmental, Health, and Safety Aspects of Engineered Nanomaterials*,[125] specifically with respect to

> the importance of a life cycle approach to assessing risks, the need for more research on human and environmental exposure to nanomaterials, better tools for measuring and tracking nanomaterials, and the need for cross-cutting informatics infrastructure for nanotechnology-related EHS research.[126]

However, PCAST expressed concerns about "a lack of integration between nanotechnology-related EHS research funded through the NNI and the kind of information policymakers need to

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[121] PCAST (acting as the NNAP), *Report to the President and Congress on the Fifth Assessment of the National Nanotechnology Initiative*, October 2014, p. 7, http://www.whitehouse.gov/sites/default/files/microsites/ostp/PCAST/pcast_fifth_nni_review_oct2014_final.pdf.

[122] PCAST, EOP, *Third Assessment,* March 12, 2010.

[123] NRC, *A Matter of Size: Triennial Review of the National Nanotechnology Initiative*, 2006.

[124] PCAST, EOP, *Fourth Assessment*, April 2012.

[125] NRC, Committee to Develop a Research Strategy for Environmental, Health, and Safety Aspects of Engineered Nanomaterials, *A Research Strategy for Environmental, Health, and Safety (EHS) Aspects of Engineered Nanomaterials (ENMs)*, 2012, http://www.nap.edu/catalog.php?record_id=13347.

[126] PCAST, EOP, *Fourth Assessment*, April 2012.

effectively manage potential risks from nanomaterials."[127] To address this concern, PCAST recommended that OSTP and the NSET Subcommittee expand the charter of the NEHI working group to enable the group to address cross-agency nanotechnology-related policy issues more broadly, and that the NNI should ensure close integration of its efforts with those of the Emerging Technologies Interagency Policy Coordination Committee (ETIPC).[128] PCAST also recommended additional funding for cross-cutting areas of EHS that promote knowledge transfer such as informatics, partnerships, and instrumentation development.[129]

In its *Third Assessment,* PCAST credited the NNI with increasing funding for EHS-focused research. Funding for EHS-related nanotechnology research across all agencies grew from $37.7 million in FY2006 to $109.9 million in FY2012. President Obama has requested $121.1 million in nanoEHS funding for FY2014.

Some advocates for increased focus on nanotechnology-related EHS issues have proposed the establishment of a separate agency or office devoted to nanotechnology EHS research, and/or to set aside a particular percentage of NNI funding for EHS research. In its *Second Assessment*, PCAST found these proposals to be "misguided" and potentially counterproductive as such approaches may direct resources away from research "on beneficial applications and on risk." The panel also concluded that nanotechnology does not raise ethical concerns unique from those accompanying other technological advances.[130]

## Societal Implications

The term "societal implications" in the context of the NNI refers to the effects, broadly speaking, that advances in nanotechnology research and application may have on individuals, groups, and society as a whole. With nanotechnology holding potential breakthroughs in areas such as materials and manufacturing, medicine and healthcare, environment and energy, biotechnology and agriculture, electronics and information technology, and national security,[131] the societal implications—including ethical, economic, and legal implications—may be both deep and widespread.

Understanding the potential societal implications of nanotechnology is considered important to federal efforts to maximize nanotechnology's potential positive effects and minimize its potential negative effects. Beginning with its first review of the NNI, PCAST stressed the importance of research aimed at understanding the societal implications of nanotechnology and recommended the NNI actively work to inform the public about nanotechnology and to confront societal issues in an open, straightforward, and science-based manner.[132]

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[127] Ibid.

[128] The Emerging Technologies Interagency Policy Coordination Committee was created jointly in 2010 by OSTP, OMB's Office of Information and Regulatory Affairs, and the Office of the United States Trade Representative. The ETIPC members include assistant secretary-level representatives from about 20 Federal agencies.

[129] PCAST, EOP, *Fourth Assessment*, April 2012.

[130] PCAST, EOP, *The National Nanotechnology Initiative: Second Assessment and Recommendations of the National Nanotechnology Advisory Panel*, May 2005, http://www.whitehouse.gov/sites/default/files/microsites/ostp/PCAST-NNAP-NNI-Assessment-2008.pdf.

[131] NSF, *Societal Implications of Nanoscience and Nanotechnology,* March 2001, http://www.wtec.org/loyola/nano/NSET.Societal.Implications/nanosi.pdf.

[132] PCAST, EOP, The National Nanotechnology Initiative at Five Years: Assessment and Recommendations of the (continued...)

PCAST has continued to stress the importance of a strong NNI program in societal implications, recommending in its *Fourth Assessment:*

> The NSET Subcommittee should develop a clear expectation and strategy for programs in the societal dimensions of nanotechnology. An effective program in societal implications would have well-defined areas of focus, clearly articulated outcomes as well as plans for assessing and evaluating those outcomes, and partnerships that leverage the value of its activities. Ultimately, the inclusion of such programs in the NNI has the goal of streamlining nanotechnology innovation and its positive impact on society, and the creation of new jobs, opportunities and a robust economy.[133]

Some critics of the NNI hold deep reservations about the ethical, societal, economic, and legal implications of nanotechnology. Some of these concerns are common to many technologies, such as the allocation of risk and benefit during manufacturing. For example, a neighborhood located near a production facility may bear risks associated with exposure to the byproducts (or products) of nanoscale manufacturing, while gaining few of the benefits. Concerns about possible adverse effects of nanoscale particles on human health and the environment resulting from their small particle size and unique characteristics may result in increased attention to such costs and benefits with respect to nanoscale material production. Currently, nanotechnology EHS risks are not well understood and may be acute, pose no more risk than other manufacturing processes, or perhaps even less.

Privacy rights are another issue associated with the products of nanotechnology. Nanotechnology may enable the production of highly sensitive, inexpensive sensors that could be deployed ubiquitously in commercial and public settings. While these sensors may allow beneficial applications, such as check-out-free purchases from stores or the monitoring of the environment for toxic substances, critics argue that they could also impinge on the privacy rights of individuals if, for example, the sensors could detect chemicals related to the use of tobacco, alcohol, or illegal substances without the permission of the individual. Such information might be later applied in law enforcement, life insurance, health insurance, or employment decisions.[134] Others express concern that the economically disadvantaged and less educated—both individuals and nations—might be unable or less able to take part in the benefits that nanotechnology products could offer.[135]

# Concluding Observations

Many expect nanotechnology to bring significant economic and societal returns. The United States was the first government to launch a national-level nanotechnology program and has invested more than any other nation. Many experts believe that, as a result of this focus and these sustained investments, the United States enjoys a technological leadership position in

(...continued)

National Nanotechnology Advisory Panel, May 2005, http://www.nano.gov/html/res/FINAL_PCAST_NANO_REPORT.pdf.

[133] PCAST, EOP, *Fourth Assessment*, April 2012.

[134] Moore, Fiona M., "Implications of Nanotechnology Applications: Using Genetics as a Lesson," *Health Law Review*, Vol. 10, No. 3, 2002. http://www.law.ualberta.ca/centres/hli/pdfs/hlr/v10_3/10.3moorefrm.pdf.

[135] Smith, Richard H., "Social, Ethical, and Legal Implications of Nanotechnology," *Societal Implications of Nanoscience and Nanotechnology* (The Netherlands: Kluwer Academic Publishers, 2001).

nanotechnology. Other nations are investing heavily and some industrialized and emerging economies have formidable capabilities in nanotechnology. Assessments of the National Nanotechnology Initiative have concluded that the effort is well-managed and has been successful in achieving its objectives so far. However, these assessments have recognized that the NNI faces a variety of challenges in ensuring that the full promise of nanotechnology is realized and that the United States remains the global leader in nanoscale science, engineering, and technology.

Congress may choose to address some or many of the issues identified in the body of this report in the course of deliberation on the reauthorization of the 21st Century Nanotechnology R&D Act of 2003 or, alternatively, in separate legislation.

The 21st Century Nanotechnology R&D Act's funding authorizations extended through FY2008. The 109th Congress, 110th Congress, 111th Congress, and 113th Congress considered legislation to reauthorize the program. If the 114th Congress opts to consider reauthorization of the act, some of the issues it may wish to consider include budget authorization levels for the covered agencies; R&D funding levels, priorities, and balance across the program component areas; administration and management of the NNI; translation of research results and early-stage technology into commercially viable applications; environmental, health, and safety issues; ethical, legal, and societal implications; education and training for the nanotechnology workforce; metrology, standards, and nomenclature; public understanding; and international dimensions. Consideration may also be given to the establishment of an independent review panel and to coordination of the timing for the NNAP assessment, the NRC assessment, and the NSET Subcommittee's strategic plan for the NNI.

# Appendix A. Selected Nanotechnology Legislation in the 113th, 112th, and 111th Congresses

## S. 2757 (113th Congress)—America COMPETES Reauthorization Act of 2014

S. 2757, the America COMPETES Reauthorization Act of 2014, was introduced on July 31, 2014, and referred to the Committee on Commerce, Science, and Transportation. The National Nanotechnology Initiative Amendments Act of 2014 is included as Subtitle B of Title VI of the bill.

Among the provisions of the bill's nanotechnology subtitle:

- The National Science and Technology Council would be directed to establish nanotechnology signature initiatives in focused areas of national importance.
- The NSTC would be required to produce a strategic plan at least once every four years. The strategic plan would specify the overarching goals for the program; near-term and long-term objectives; and the metrics to be used for assessing progress toward such objectives. In addition, the strategic plan would describe how the program intends to allocate funding for interagency nanotechnology projects; encourage and support interdisciplinary research and development in nanotechnology; and support the engineering, scale-up, and commercialization of nanotechnology necessary to move results out of the laboratory and into applications.
- The federal multi-agency nanotechnology effort would be officially designated as the "National Nanotechnology Initiative."
- The Director of OSTP would be required to appoint the NNCO director to serve as a co-chair of the NSET Subcommittee of the NSTC.
- The National Nanotechnology Advisory Panel (currently PCAST, as designated by the President) would be required to conduct reviews at least once every four years.
- The NNCO would be required to engage the National Academy of Sciences in a review of the program every four years. The review is to include: a review of the research priorities of the program, including whether the amount and allocation of funding among program component areas and nanotechnology signature initiatives is appropriate to accomplish the program's goals and objectives; an evaluation of the program's management and coordination across agencies and disciplines, including the effectiveness of the NNCO in providing technical and administrative support to the program; and an assessment of the program's success in transferring technology to the private sector and recommendations for improving technology demonstration, transfer, and commercialization.
- With respect to technology transfer, the NNCO director and NNI agencies would be encouraged to inform the public about the science, technology, and benefits of nanotechnology; and the commercial products enabled by nanotechnology.

- NNI agencies would be encouraged to provide access to federally owned or operated nanotechnology research centers or designated user facilities to a representative of industry, academia, or other potential user for the purpose of transferring research results; demonstrating models of nanoscale- or nanotechnology-enabled products or devices; or demonstrative processes for determining proof of concept.
- Agency heads would be authorized to reimburse the travel expenses of an employee of the agency who participates in the development of domestic and international standards for nanotechnology.
- The NNCO would serve as a central repository to collect, track, analyze, and report data regarding the impact of nanotechnology on the U.S. economy; publications concerning nanotechnology; patents relating to nanotechnology; educational activities relating to nanotechnology; and matters concerning the U.S. workforce and nanotechnology.
- The NSF in cooperation with the Secretary of Education and Secretary of Labor, working with the NNCO, would be required to evaluate the investments of the NNI in education and workforce training in a report to Congress.
- The Council, working with the NNCO director, would be required to periodically convene meetings for nanotechnology related centers, networks, and user facilities to share best practices regarding strategic planning, intellectual property management, outreach to industry; and technology demonstration, transfer, and commercialization.

Congress also would express its sense that the NSTC should coordinate development by the NNI agencies of performance measures, targets, timeframes, cost estimates and available resources for nanotechnology environment, health, and safety research that align with the research needs of the NNI, consistent with the agencies' respective statutory authorities, and to provide the information in publicly available reports.

## H.R. 4159 (113th Congress)—America Competes Reauthorization Act of 2014 (including Subtitle B, the National Nanotechnology Initiative Amendments Act of 2014)

H.R. 4159 (113th Congress), the America Competes Reauthorization Act of 2014, was introduced on March 6, 2014, and referred to the Committee on Science, Space, and Technology and the Committee on Higher Education and the Workforce. The National Nanotechnology Initiative Amendments Act of 2014 is included as Subtitle B of Title I of the bill.

Among the provisions of the bill's nanotechnology subtitle:

- The National Science and Technology Council would be required to publish a strategic plan every three years to guide the activities of the NNI. The strategic plan is required to include near-term and long-term objectives for the NNI, the anticipated timeframe for achieving the near-term objectives, and the metrics to be used for assessing progress toward the objectives.

- Federal agencies would be directed to support nanotechnology standards development efforts.
- Funding for the National Nanotechnology Coordination Office would be provided by each NNI agency in proportion to its share of total NNI funding for the previous fiscal year; the director of the NNCO would be authorized to establish a minimum contribution level or other exception for agencies whose share of total funding is below a threshold level.
- The NNCO would be required to maintain (1) a publicly accessible database of NNI-funded environmental, health, and safety (EHS) activities (2) links to agency information on nanotechnology facilities that are accessible to individuals from academic institutions and industry.
- The National Nanotechnology Advisory Panel would be required to produce triennial reviews of the NNI, and to do so, to the extent practicable, in the year following each review by the National Research Council.
- The director of the NNCO would be required to enter into an arrangement with the National Research Council of the National Academies of Sciences to produce a triennial report on the NNI, including an evaluation of research priorities, technical content, scientific and technological accomplishments, success in technology transfer, and adequacy of the NNI's activities addressing ethical, legal, environmental, and other appropriate societal concerns, including human health.
- The Director of the President's Office of Science and Technology Policy would be required to designate a Coordinator for Environmental, Health, and Safety Research to provide oversight of coordination, planning, and budget prioritization of research and other activities related to nanotechnology EHS research. The coordinator would be required to develop and update a research plan triennially.
- NSET agencies would be encouraged to introduce nanoscale science, engineering, and technology into undergraduate science and engineering education by supporting the development of courses of instruction or modules to existing courses, faculty professional development, and acquisition of equipment and instrumentation suitable for undergraduate education and research in nanotechnology. These educational efforts would be coordinated by the NSET Subcommittee and the NSTC Committee on Science, Technology, Engineering, and Math Education (CoSTEM).
- Any nanotechnology educational activity supported under the NNI's Education and Societal Dimensions program component area would be required to include an educational component on the EHS aspects of nanotechnology.
- Agencies supporting nanotechnology research would be required to provide remote access to their facilities via the Internet by secondary school students and teachers.
- Agencies supporting nanotechnology research would be required to provide access to their nanotechnology research facilities to companies for the purpose of assisting the companies in the development of prototypes of nanoscale products, devices, or processes for determining proof-of-concept.

- The NNI would be directed to support Signature Initiatives—nanotechnology research and development activities directed toward application areas that have the potential for significant contributions to national economic competitiveness and for other significant societal benefits (e.g., nanoelectronics, energy efficiency, solar energy, health care, and water remediation and purification).
- The NNI would be directed to support nanomanufacturing research, including the development of instrumentation and tools required for the rapid characterization of nanoscale materials and for monitoring of nanoscale manufacturing processes, and approaches and techniques for scaling the synthesis of new nanoscale materials to achieve industrial-level production rates.
- Certain NNI centers would be directed to support "Green Manufacturing" activities, including research on methods and approaches to develop environmentally benign nanoscale products and nanoscale manufacturing processes, fostering the transfer of research results to industry, and providing for the education of scientists and engineers through interdisciplinary studies in the principles and techniques for the design and development of environmentally benign nanoscale products and processes.

## H.R. 2996 (113th Congress)—Revitalize American Manufacturing and Innovation Act of 2014

H.R. 2996, the Revitalize American Manufacturing and Innovation Act of 2014, was introduced on August 2, 2014, reported by the House Committee on Science, Space, and Technology on September 15, 2014, and passed by the House by voice vote on September 15, 2014. The primary purpose of the bill is to establish a Network for Manufacturing Innovation Program. Centers with a nanotechnology focus would qualify under the bill as a "center for manufacturing innovation."

## H.R. 1385 (113th Congress)—Safe Cosmetics and Personal Care Products Act of 2013

H.R. 1385, the Safe Cosmetics and Personal Care Products Act of 2013, was introduced on March 21, 2013, and referred to the Committee on Energy and Commerce and the Committee on Education and the Workforce. The nanotechnology-related provisions of this bill are essentially identical to those included in both H.R. 2359 (112th Congress) and H.R. 5786 (111th Congress).

Among its provisions are several related to nanotechnology. Under the bill, the Secretary of HHS would be authorized to require that minerals and other particulate ingredients be labeled as "nano-scale" on a cosmetic ingredient label or list if not less than 1% of the ingredient particles in the cosmetic are 100 nanometers or smaller in not less than 1 dimension, and that other ingredients in a cosmetic be designated with scale-specific information on a cosmetic ingredient label or list if such ingredients possess scale-specific hazard properties. The bill would also require the Secretary of HHS to monitor developments in the scientific understanding of any adverse health effects related to the use of nanotechnology in the formulation of cosmetics and to consider scale specific hazard properties of ingredients when reviewing or evaluating the safety of cosmetics and ingredients. In addition, the bill would require manufacturers to submit to the Secretary a statement for each cosmetic that includes an ingredient list, including the particle size range of any nanoscale cosmetic ingredients.

## H.R. 394 (113th Congress)—Nanotechnology Advancement and New Opportunities Act

H.R. 394, the Nanotechnology Advancement and New Opportunities Act, was introduced on January 23, 2013, and subsequently referred to the House Committee on Science, Space, and Technology, and to the Committees on Energy and Commerce, Ways and Means, and Homeland Security. The purpose of the bill is to ensure the development and responsible stewardship of nanotechnology. The provisions of this bill are essentially identical to those in both H.R. 2749 (112th Congress) and H.R. 820 (111th Congress). The bill would:

- establish a $100 million Nanomanufacturing Investment Partnership at the Department of Commerce to work with private investors to advance the commercialization of nanomanufacturing technologies and to increase the commercial application of federally supported research results;
- establish a 15% tax credit, taken over five years, for the purchase of up to $10 million of stock in qualified nanotechnology companies;
- establish a grant program within the DOC to support the establishment and development of nanotechnology incubators by non-profit entities and degree-granting institutions;
- require the NNCO Director to prepare a report to Congress on a nanotechnology research strategy for government and industry that will ensure the development and responsible stewardship of nanotechnology;
- provide a tax credit of 50% for nanotechnology education and training expenses for businesses and individuals;
- authorize an annual appropriation of $15 million for FY2012 through FY2015 for the NSF to conduct a grant program for the development of curriculum materials for interdisciplinary nanotechnology courses at institutions of higher education;
- direct the NSF to establish, through its Advanced Technological Education program, a program to encourage manufacturing companies to enter into partnerships with occupational training centers for the development of training to support nanomanufacturing; and
- direct the Secretary of Energy to submit a report to Congress containing a strategy for increasing interaction among scientists and engineers at DOE national laboratories and the informal science education community to prepare appropriate exhibits for school age children and the general public.

In addition, the bill would have amended the 21st Century Nanotechnology Research and Development Act of 2003 to:

- authorize $10 million for NSF to establish a center for the development of computer-aided design tools for nanotechnology applications;
- authorize an annual appropriation of $30 million for the Department of Energy to conduct a grant program for nanotechnology research to address the need for "clean, cheap, renewable energy";

- authorize an annual appropriation of $30 million for the Environmental Protection Agency for a grant program for nanotechnology research to address technologies for the remediation of pollution and other environmental protection technologies;
- authorize an annual appropriation of $30 million for the Department of Homeland Security to conduct a grant program for nanotechnology research to address the need for sensors and materials related to homeland security needs; and
- authorize an annual appropriation of $30 million for the Department of Health and Human Services to conduct a grant program for nanotechnology research to address health-related applications.

## S. 3187/P.L. 112-144 (112th Congress)—Food and Drug Administration Safety and Innovation Act

S. 3187, the Food and Drug Administration Safety and Innovation Act, was introduced May 15, 2012, and became law (P.L. 112-144) on July 9, 2012. Among its provisions, P.L. 112-144 directs the Secretary of Health and Human Services to

> intensify and expand activities related to enhancing scientific knowledge regarding nanomaterials included or intended for inclusion in products regulated under the Federal Food, Drug, and Cosmetic Act or other statutes administered by the Food and Drug Administration, to address issues relevant to the regulation of those products, including the potential toxicology of such nanomaterials, the potential benefit of new therapies derived from nanotechnology, the effects of such nanomaterials on biological systems, and the interaction of such nanomaterials with biological systems.

In this regard, the HHS Secretary is authorized to

> (1) assess scientific literature and data on general nanomaterials interactions with biological systems and on specific nanomaterials of concern to the Food and Drug Administration;
>
> (2) in cooperation with other federal agencies, develop and organize information using databases and models that will facilitate the identification of generalized principles characteristics regarding the behavior of classes of nanomaterials with biological systems;
>
> (3) promote Food and Drug Administration programs and participate in collaborative efforts, to further the understanding of the science of novel properties of nanomaterials that might contribute to toxicity;
>
> (4) promote and participate in collaborative efforts to further the understanding of measurement and detection methods for nanomaterials;
>
> (5) collect, synthesize, interpret, and disseminate scientific information and data related to the interactions of nanomaterials with biological systems;
>
> (6) build scientific expertise on nanomaterials within the Food and Drug Administration, including field and laboratory expertise, for monitoring the production and presence of nanomaterials in domestic and imported products regulated under this act;

(7) ensure ongoing training, as well as dissemination of new information within the centers of the Food and Drug Administration, and more broadly across the Food and Drug Administration, to ensure timely, informed consideration of the most current science pertaining to nanomaterials;

(8) encourage the Food and Drug Administration to participate in international and national consensus standards activities pertaining to nanomaterials; and

(9) carry out other activities that the Secretary determines are necessary and consistent with the purposes described in paragraphs (1) through (8).

## S. 1662 (112th Congress)—Nanotechnology Regulatory Science Act of 2011

S. 1662, the Nanotechnology Regulatory Science Act of 2011, was introduced on October 6, 2011, and referred to the Senate Committee on Health, Education, Labor, and Pensions. The bill would have amended the Federal Food, Drug, and Cosmetic Act (FFDCA) to require the Secretary of Health and Human Services to establish within the Food and Drug Administration a program for the scientific investigation of nanomaterials included or intended for inclusion in products regulated under the FFDCA to address the potential toxicology of such materials; the effects of such materials on biological systems; and the interaction of such materials with biological systems.

## H.R. 2749 (112th Congress)—Nanotechnology Advancement and New Opportunities Act

H.R. 820 (111th Congress), the Nanotechnology Advancement and New Opportunities Act, was introduced on February 3, 2009, and referred to four House committees: the Committee on Science and Technology, the Committee on Energy and Commerce, the Committee on Ways and Means, and the Committee on Homeland Security. The purpose of the bill was to ensure the development and responsible stewardship of nanotechnology. The provisions of this bill are essentially identical to those of H.R. 394, introduced in the 113th Congress (described above).

## H.R. 2359 (112th Congress)—Safe Cosmetics Act of 2011

H.R. 2359, the Safe Cosmetics Act of 2011, was introduced on June 24, 2011, and referred to two House committees: the Committee on Energy and Commerce and the Committee on Education and the Workforce. The nanotechnology-related provisions of this bill are essentially identical to those of H.R. 1385, introduced in the 113th Congress (described above).

## S. 1867 (112th Congress)—National Defense Authorization Act for Fiscal Year 2012

S. 1867, the National Defense Authorization Act for Fiscal Year 2012, was introduced on November 11, 2011, and passed by the Senate on December 1, 2011. Section 5501 of the bill would have expanded the research topics given special consideration under the SBIR and STTR

programs to include rare diseases, security, energy, transportation, or improving the security and quality of the water supply of the United States, and the efficiency of water delivery systems and usage patterns in the United States (including the territories of the United States) through the use of technology (to the extent that the projects relate to the mission of the federal agency), broad research topics, and topics that further one or more critical technologies or research priorities; research topics identified in the NNI's strategic plan (required under Section 2(c)(4) of the 21st Century Nanotechnology Research and Development Act); and in any report of the National Science and Technology Committee's Committee on Technology focused on areas of nanotechnology identified in the strategic plan.

## S. 493 (112th Congress)—SBIR/STTR Reauthorization Act of 2011

S. 493, the SBIR/STTR Reauthorization Act of 2011, was introduced in the Senate on March 4, 2011, and referred to the Committee on Small Business and Entrepreneurship. The bill was reported with amendments but without a written report on March 9, 2011. On May 4, 2011, a cloture motion on the bill failed. As part of the larger purpose of reauthorizing the SBIR and STTR programs, S. 493 would have required agencies with SBIR and STTR programs to give consideration to research topics identified in the NSET Subcommittee's national nanotechnology strategic plan mandated by P.L. 108-153 and related documents, and to give special priority to applications for the support of projects related to nanotechnology and other specified fields of application. Section 501 (Research Topics and Program Diversification) of S. 493, which contained the nanotechnology related provisions, was incorporated in its entirety in S. 1867, the National Defense Authorization Act for Fiscal Year 2012. This bill was passed by the Senate, but the provision was not included in the final enacted version of the House bill (P.L. 112-81).

## Title I, Subtitle A, H.R. 5116 (111th Congress)—National Nanotechnology Initiative Amendments Act of 2010

The provisions of Title I, Subtitle A of H.R. 5116 (111th Congress), the National Nanotechnology Initiative Amendments Act of 2010, were nearly identical to H.R. 554 (111th Congress) (see "H.R. 554 (111th Congress)—National Nanotechnology Initiative Amendments Act of 2009" below). H.R. 5116 changed the name of the act from the "National Nanotechnology Initiative Amendments Act of 2009," to "National Nanotechnology Initiative Amendments Act of 2010," and removed the term "interdisciplinary" from a provision establishing "green nanotechnology" research centers. The Senate removed this title before the bill was enacted.

## H.R. 554 (111th Congress)—National Nanotechnology Initiative Amendments Act of 2009

H.R. 554 (111th Congress), the National Nanotechnology Initiative Amendments Act of 2009, was introduced on January 15, 2009, and passed by the House of Representatives on February 11, 2009. The bill was referred to the Senate Commerce, Science, and Transportation Committee on February 12, 2009. The purpose of the bill was to authorize activities for support of nanotechnology R&D and for other purposes. Among its provisions, the bill would have amended the 21st Century Nanotechnology Research and Development Act of 2003 to:

- require the NSTC triennial strategic plan to include near-term and long-term objectives, the anticipated timeframe for achieving near-term objectives, and metrics for assessing progress; cooperative and collaborative activities in R&D and technology transition supported by the states; and proposed research in areas of national priority;
- require the NSTC annual nanotechnology report supplementing the President's budget request to include a breakout of spending for the development and acquisition of research facilities and instrumentation for each program component area, and a breakout of spending on all activities related to ethical, legal, environmental, and societal implications;
- direct NNP agencies to support the activities of committees involved in the development of standards for nanotechnology and allow agencies to reimburse the travel costs of scientists and engineers who participate in activities of such committees;
- direct the agencies to fund the National Nanotechnology Coordination Office, and to do so in proportion to each agency's share of the previous year's NNP budget;
- require the NNCO to develop and maintain a publicly accessible database of projects funded under the Environmental, Health, and Safety, the Education and Societal Dimensions, and the Nanomanufacturing program component areas;
- require the NNCO to develop, maintain, and publicize information on nanotechnology facilities supported by the NNP, including at a minimum the terms and conditions for the use of each facility, a description of the capabilities of the instruments and equipment available for use at the facility, and a description of the technical support available to assist users of the facility;
- require the establishment of a National Nanotechnology Advisory Panel (NNAP) "as a distinct entity." Currently, under the provisions of presidential Executive Order 13349, the President's Council of Advisors on Science and Technology serves as the NNAP;[136]
- direct the NNCO to enter into an arrangement with the National Research Council to conduct a triennial review of the NNP, and authorizes funds for FY2010, FY2011, and FY2012; and
- define nanotechnology as "the science and technology that will enable one to understand, measure, manipulate, and manufacture at the nanoscale, aimed at creating materials, devices, and systems with fundamentally new properties or functions," and define nanoscale as "one or more dimensions of between approximately 1 and 100 nanometers."

In addition, the bill would have:

- required the designation of a White House Office of Science and Technology Policy associate director to serve as the "Coordinator for Societal Dimensions of Nanotechnology" and would charge the coordinator with convening and chairing

[136] Executive Order 13349, http://edocket.access.gpo.gov/cfr_2005/janqtr/3CFR13349.htm.

a panel of federal agency representatives and others to develop, maintain, implement, and monitor an annual EHS research plan that includes, among other things, standards related to nanotechnology nomenclature; standards for methods and procedures for detecting, measuring, monitoring, sampling, and testing engineered nanoscale materials for environmental, health, and safety impacts; and standard reference materials for EHS testing;

- required the National Science Foundation to provide grants to establish Nanotechnology Education Partnerships to recruit and help prepare secondary school students to pursue postsecondary level courses of instruction in nanotechnology;
- directed the NSTC to establish an Education Working Group under the NSET Subcommittee to coordinate, prioritize, and plan NNP educational activities;
- directed certain NNP agencies to provide companies access to their supported facilities to assist in the development of prototypes of nanoscale products, devices, or processes for determining proof of concept;
- directed NNP agencies to encourage nanotechnology-related submissions to their Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs;
- directed NIST to encourage nanotechnology-related submissions to its Technology Innovation Program (TIP), and directs the TIP advisory Board to provide advice to NIST to accomplish this, and to provide an assessment of the adequacy of TIP resources allocated to nanotechnology related projects;
- directed the NSTC to actively pursue industry liaison groups for all industries;
- directed the NNP to coordinate and leverage federal investments with nanotechnology research, development, and technology transition initiatives supported by the States;
- directed the NNP to support nanotechnology R&D activities directed toward application areas that have the potential for significant contributions to national economic competitiveness and for other significant societal benefits, such as nano-electronics, energy efficiency, health care, and water remediation and purification;
- directed the NNP to support research on the development of instrumentation and tools required for the rapid characterization of nanoscale materials and for monitoring of nanoscale manufacturing processes, and to support approaches and techniques for scaling the synthesis of new nanoscale materials to achieve industrial-level production rates; and
- directed certain NNP-supported interdisciplinary research centers to support research on methods and approaches to environmentally benign nanoscale products and nanoscale manufacturing processes, as well as related technology transfer and education activities.

## S. 1482 (111th Congress)—National Nanotechnology Amendments Act of 2009

S. 1482 (111th Congress), the National Nanotechnology Amendments Act of 2009, was introduced on July 21, 2009, and referred to the Senate Commerce, Science, and Transportation Committee. The purpose of the bill was to reauthorize the 21st Century Nanotechnology Research and Development Act and to expand the scope of the National Nanotechnology Program (NNP).

Among its provisions, the bill would have:

- required the NNP to solicit and draw upon the perspectives of the industrial community to promote the rapid commercial development of nanoscale-enabled devices, systems, and technologies and to coordinate research in determining the key physical and chemical characteristics of nanoparticles and nanomaterials that may pose environmental, health, and safety risks;
- required the NNCO and other appropriate agencies and councils to issue guidance to agencies that describes a strategy for transitioning research into commercial products and technologies and how the program will coordinate or conduct research on the environmental, health, and safety issues related to nanotechnology;
- required the NSTC triennial strategic plan to include near-term and long-term objectives, the anticipated timeframe for achieving near-term objectives, and metrics for assessing progress; cooperative and collaborative activities in R&D and technology transition supported by the states; how the NNP intends to encourage and support interdisciplinary research; and proposed research in areas of national priority;
- encouraged joint interagency solicitation of grant applications in high priority, multi-disciplinary research areas;
- required participating agencies to support the activities of the committees of standards setting bodies involved in the development of standards for nanotechnology;
- required each participating agency to provide funds to support the work of the NNCO. Authorizes appropriations to (1) NIST for the development of nanotechnology standards; and (2) NSF, for use by the NNCO, to develop and maintain a public information database of NNP projects in EHS; education; public outreach; ethical, legal, and other societal issues; and of nanotechnology facilities accessible for use by individuals from academia and industry;
- made the National Nanotechnology Advisory Panel (NNAP) a distinct entity, and requires the NNAP to establish a subpanel to enable it to assess whether societal, ethical, legal, environmental, and workforce concerns are adequately addressed by the NNP;
- revised provisions for triennial external review of the NNP;
- required the designation of a "coordinator for societal dimensions of nanotechnology," within OSTP, to convene a panel to develop a research plan, and requires the coordinator to enter into an arrangement with the National

Science Board to create a report that identifies the broad goals and needs of EHS researchers;

- directed the NSTC to establish an interagency Education Working Group to coordinate, prioritize, and plan formal and informal educational activities supported under the NNP, including activities to help participants understand the EHS implications of nanotechnology;
- provided for one or more grants to establish Nanotechnology Education Partnerships to recruit and help prepare secondary school students to pursue postsecondary level courses in nanotechnology;
- required agencies supporting nanotechnology research facilities to provide access to representatives from industry and other stakeholders for the transfer of research results or assist in developing proof-of-concept prototypes of nanoscale products, devices, or processes;
- directed NIST, in its Technology Innovation Program, and all agencies with Small Business Innovation Research (SBIR) and Small Business Technology Transfer (STTR) programs, to encourage the submission of nanotechnology related grant proposals;
- set, for the NNP, the objective of establishing industry liaison groups for all industry sectors that would benefit from nanotechnology applications;
- required coordination and leveraging of federal investments with nanotechnology research, development, and technology transition initiatives supported by state governments;
- required the NNP to support nanotechnology R&D in areas of national importance (e.g., economic competitiveness, energy production, water purification, agriculture, and health care; in environmental, health, and safety research on the risks of nanoparticles) and in ethical, legal, and societal issues related to nanotechnology;
- required the NNP to support a wide array of research in support of nanomanufacturing;
- required the director of the NNCO to review and report on nanomanufacturing research and research facilities;
- required an NNAP review of the nanomanufacturing program component area and the capabilities of nanotechnology research facilities supported by the NNP;
- set forth provisions regarding NNP nanoscale characterization and metrology research; and
- required deliberative public input in the decision making processes affecting policies for the research, development, and use of nanotechnology, and authorizes $2.0 million for the NNCO to carry out this responsibility.

## S. 596 (111th Congress)—Nanotechnology Innovation and Prize Competition Act of 2009

S. 596 (111th Congress), the Nanotechnology Innovation and Prize Competition Act of 2009, was introduced on March 16, 2009, and referred to the Senate Commerce, Science, and Transportation Committee. The purpose of the bill was to establish an award program to honor achievements in nanotechnology. Under the bill, the Department of Commerce's National Institute of Standards and Technology is directed to award prizes to individuals and companies for achievement in one or more of the following areas: improvement of the environment, consistent with EPA's Twelve Principles of Green Chemistry; development of alternative energy that has the potential to lessen the dependence of the United States on fossil fuels; and/or improvement of human health, consistent with regulations promulgated by the FDA. The bill would have authorized financial prizes for being the first to achieve a specific criteria, as well as recognition prizes, made as part of the previously established National Technology and Innovation Medal award program. The bill would have authorized $2 million annually for the financial prizes as well as $750,000 annually for administration of the prize competitions.

## H.R. 820 (111th Congress)—Nanotechnology Advancement and New Opportunities Act

H.R. 820 (111th Congress), the Nanotechnology Advancement and New Opportunities Act, was introduced on February 3, 2009, and referred to four House committees: the Committee on Science and Technology, the Committee on Energy and Commerce, the Committee on Ways and Means, and the Committee on Homeland Security. The purpose of the bill was to ensure the development and responsible stewardship of nanotechnology. The provisions of this bill are essentially identical to those of H.R. 394, introduced in the 113th Congress (described above).

## H.R. 2647 (111th Congress)—National Defense Authorization Act for Fiscal Year 2010

Section 242 of the National Defense Authorization Act for Fiscal Year 2010 (H.R. 2647, P.L. 111-84) amends the Department of Defense's nanotechnology reporting responsibilities to align with those required of other agencies under the 21st Century Nanotechnology Research and Development Act (P.L. 108-153). H.R. 2647 was signed into law on October 28, 2009.

## S. 3117 (111th Congress)—Promote Nanotechnology in Schools Act

S. 3117 (111th Congress), the Promote Nanotechnology in Schools Act, was introduced on March 15, 2010, and referred to the Senate Committee on Health, Education, Labor, and Pensions. The purpose of the bill was to strengthen the capacity of eligible institutions (i.e., secondary schools, community colleges, two-year and four-year institutions of higher education, and informal learning science centers) to provide instruction in nanotechnology. The bill would have authorized a program at the National Science Foundation for this purpose that would offer eligible institutions grants of up to $400,000 (subject to a 25% match from non-federal sources) to assist in the purchase and maintenance of nanotechnology equipment and software, to develop and provide educational services, and to support teacher education and certification. The bill

would have authorized $15 million for FY2010 and "such sums as may be necessary" for FY2011 through FY2013.

## H.R. 4502 (111th Congress)—Nanotechnology Education Act

H.R. 4502 (111th Congress), the Nanotechnology Education Act, was introduced on February 19, 2010, and referred to the House Committee on Science and Technology's Subcommittee on Research and Science Education. The purpose of the bill was to strengthen the capacity of eligible institutions (i.e., secondary schools, community colleges, four-year institutions of higher education, and informal learning science centers) to provide instruction in nanotechnology. The bill would have authorized a program for this purpose at the National Science Foundation that would offer eligible institutions grants of up to $400,000 (subject to a 25% match from non-federal sources) to assist in the purchase and maintenance of nanotechnology equipment and software, to develop and provide educational services, and to support teacher education and certification. The bill would have authorized $40 million for FY2011 and "such sums as may be necessary" for FY2012 through FY2014.

## S. 2942 (111th Congress)—Nanotechnology Safety Act of 2010

S. 2942 (111th Congress), the Nanotechnology Safety Act of 2010, was introduced on January 21, 2010, and referred to the Senate Committee on Health, Education, Labor, and Pensions. The bill would have required the Secretary of Health and Human Services to establish within 180 days a program for the scientific investigation of nanoscale materials included or intended for inclusion in FDA-regulated products, to address the potential toxicology of such materials, the effects of such materials on biological systems, and interaction of such materials with biological systems. The bill would have authorized $25 million per year for fiscal years 2011 to 2015.

## H.R. 5786 (111th Congress)—Safe Cosmetics Act of 2010

H.R. 5786 (111th Congress), the Safe Cosmetics Act of 2010, was introduced on July 20, 2010, and referred to the House Committee on Energy and Commerce and the House Committee on Education and Labor. The nanotechnology-related provisions of this bill are essentially identical to those of H.R. 1385, introduced in the 113th Congress (described above).

# Appendix B. Description of Program Component Areas In Use for FY2006 to FY2013

### *Fundamental Phenomena and Processes*

Fundamental Phenomena and Processes includes investments in the discovery and development of fundamental knowledge pertaining to the new phenomena in the physical, biological, and engineering sciences that occur at the nanoscale, as well as in understanding and articulation of scientific and engineering principles related to nanoscale structures, processes, and mechanisms.

### *Nanomaterials*

Nanomaterials includes research investments to discover novel nanoscale and nanostructured materials. This PCA also attempts to understand the properties of nanomaterials, and supports R&D to enable the design and synthesis, in a controlled manner, of nanoscale materials with targeted properties.

### *Nanoscale Devices and Systems*

Nanoscale Devices and Systems includes R&D investments that apply nanoscale science and engineering principles to create novel devices and systems or to improve existing ones. It also includes the use of nanoscale or nanostructured materials to achieve improved performance or new functionality. To meet this definition, the enabling science and technology must be at the nanoscale, but the systems and devices are not restricted to that size.

### *Instrumentation Research, Metrology, and Standards*

Instrumentation Research, Metrology, and Standards includes R&D investments for development of tools needed to advance nanotechnology research and commercialization. Instrumentation for characterization, measurement, synthesis, and design of nanotechnology materials, structures, devices, and systems is funded through this PCA. R&D and other activities related to development of standards, including standards for nomenclature, materials, characterization, testing, and manufacture, are also in this PCA.

### *Nanomanufacturing*

Nanomanufacturing R&D supports the development of scalable, reliable, cost-effective manufacturing of nanoscale materials, structures, devices, and systems. It also includes R&D and integration of ultra-miniaturized top-down processes and complex bottom-up processes.[137]

[137] Top-down processes are those that achieve design features by removing material from a larger block of material; bottom-up processes begin with smaller building blocks (atoms or molecules) and achieve design features by putting them together, possibly using self-assembly or nanoscale additive manufacturing.

### *Major Research Facilities and Instrumentation Acquisition*

Major Research Facilities and Instrumentation Acquisition includes investments in the establishment and ongoing operations of user facilities and networks, the acquisition of major instrumentation, and other activities related to infrastructure for the conduct of nanoscale science, engineering, and technology R&D.

### *Societal Dimensions*

Under the 2007 NNI Strategic Plan, the Societal Dimensions PCA was divided into two separate PCAs: Environment, Health, and Safety, and Education and Societal Dimensions.

### *Environment, Health, and Safety*

Environment, Health, and Safety addresses research primarily directed at understanding the environmental, health, and safety impacts of nanotechnology development and corresponding risk assessment, risk management, and methods for risk mitigation.

### *Education and Societal Dimensions*

Education and Societal Dimensions addresses education-related activities such as development of materials for schools, undergraduate programs, technical training, and public communication, including outreach and engagement. Such activities include research directed at identifying and quantifying the broad implications of nanotechnology for society, including social, economic, workforce, educational, ethical, and legal implications.

# Appendix C. Selected Reports on the National Nanotechnology Initiative

## Reports of the Nanoscale Science, Engineering, and Technology Subcommittee of the National Science and Technology Council

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*Environmental, Health, and Safety Research Strategy*, October 2011. http://nano.gov/sites/default/files/pub_resource/nni_2011_ehs_research_strategy.pdf

*Policy Principles for the U.S. Decision-Making Concerning Regulation and Oversight of Applications of Nanotechnology and Nanomaterials*, June 2011. http://www.whitehouse.gov/sites/default/files/omb/inforeg/for-agencies/nanotechnology-regulation-and-oversight-principles.pdf

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*Regional, State, and Local Initiatives in Nanotechnology: Report of the National Nanotechnology Initiative Workshop*, February 2011. http://nano.gov/sites/default/files/pub_resource/nni_2012_budget_supplement.pdf

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*National Nanotechnology Initiative Signature Initiative: Nanotechnology for Solar Energy Collection and Conversion*, July 2010. http://nano.gov/sites/default/files/pub_resource/nnisiginitsolarenergyfinaljuly2010.pdf

National Nanotechnology Initiative Signature Initiative: Sustainable Nanomanufacturing – Creating the Industries of the Future, July 2010. http://nano.gov/sites/default/files/pub_resource/nni_siginit_sustainable_mfr_revised_nov_2011.pdf

*National Nanotechnology Initiative Signature Initiative: Nanoelectronics for 2020 and Beyond,* July 2010. http://nano.gov/sites/default/files/pub_resource/nni_siginit_nanoelectronics_jul_2010.pdf

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*Communicating Risk in the 21st Century: The Case of Nanotechnology, February 2010.* http://nano.gov/sites/default/files/pub_resource/berube_risk_white_paper_feb_2010.pdf

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*Nanotechnology in Space Exploration*, August 2004. http://nano.gov/sites/default/files/pub_resource/space_exploration_rpt_0.pdf

*Nanoscience Research for Energy Needs: Report of the National Nanotechnology Initiative Grand Challenge Workshop*, March 2004. http://nano.gov/sites/default/files/nni_energy_rpt.pdf

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# Appendix D. List of NNI and Nanotechnology-Related Acronyms

| | |
|---|---|
| **ASTRA** | Alliance for Science and Technology Research in America |
| **CNST** | Center for Nanoscale Science and Technology |
| **CS** | Committee on Science |
| **CT** | Committee on Technology |
| **CSREES** | Cooperative State Research, Education, and Extension Service |
| **DHHS** | Department of Health and Human Services |
| **DHS** | Department of Homeland Security |
| **DOC** | Department of Commerce |
| **DOD** | Department of Defense |
| **DOE** | Department of Energy |
| **DOJ** | Department of Justice |
| **DOT** | Department of Transportation |
| **EHS** | Environmental, health, and safety |
| **ELSI** | Ethical, legal, and societal implications |
| **EPA** | Environmental Protection Agency |
| **EOP** | Executive Office of the President |
| **EPSCoR** | Experimental Program to Stimulate Competitive Research |
| **FFDCA** | Federal Food, Drug, and Cosmetic Act |
| **FHWA** | Federal Highway Administration |
| **GIN** | Global Issues in Nanotechnology working group |
| **ISO** | International Standards Organization |
| **IWGN** | Interagency Working Group on Nanotechnology |
| **NASA** | National Aeronautics and Space Administration |
| **NCI** | National Cancer Institute |
| **NEHI** | National Environmental and Health Implications working group |
| **NGO** | Non-governmental organization |
| **NIH** | National Institutes of Health |
| **NILI** | National Innovation and Liaison with Industry working group |
| **NIOSH** | National Institute of Occupational Safety and Health |
| **NIST** | National Institute of Standards and Technology |
| **NNAP** | National Nanotechnology Advisory Panel |
| **NNCO** | National Nanotechnology Coordination Office |
| **NNI** | National Nanotechnology Initiative |
| **NNIN** | National Nanotechnology Infrastructure Network |
| **NNN** | National Nanomanufacturing Network |

| | |
|---|---|
| **NNP** | National Nanotechnology Program |
| **NPEC** | Nanotechnology Public Engagement and Communications working group |
| **NRC** | National Research Council |
| **NSET** | Nanoscale Science, Engineering and Technology subcommittee |
| **NSF** | National Science Foundation |
| **NSEC** | Nanoscale Science and Engineering Center |
| **NSI** | Nanotechnology Signature Initiative |
| **NSRC** | Nanoscale Science Research Centers |
| **NSTC** | National Science and Technology Council |
| **OECD** | Organization for Economic Cooperation and Development |
| **OMB** | Office of Management and Budget |
| **OSTP** | Office of Science and Technology Policy |
| **PCA** | Program Component Areas |
| **PCAST** | President's Council of Advisors on Science and Technology |
| **R&D** | Research and development |
| **SBIR** | Small Business Innovation Research |
| **STTR** | Small Business Technology Transfer Research |
| **TSA** | Transportation Safety Administration |
| **USDA** | U.S. Department of Agriculture |
| **USPTO** | U.S. Patent and Trademark Office |

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